Coastal and Estuarine Processes

http://ecowin.org/aulas/mega/pce

Course overview

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Coastal and Estuarine Processes

http://ecowin.org/aulas/mega/pce

Objectives and Learning Outcomes

Understand

- General functioning of coastal systems, including circulation and biogeochemical cycles
- Main ecological components and their interactions
- Social and economic relevance of marine ecosystems
- Legal instruments for marine management within the European Union, and their application

Apply

Analyse and interpret data on coastal systems.

Participate in the planning of management actions.

Use models of moderate complexity.

Coastal and Estuarine Processes

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Physical Interactions

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Lecture outline

- General characteristics of seawater
- Ocean morphology and bathymetry
- Vertical structure of the sea
- Surface currents
- Tides and inshore circulation
- Estuaries
- Small-scale processes

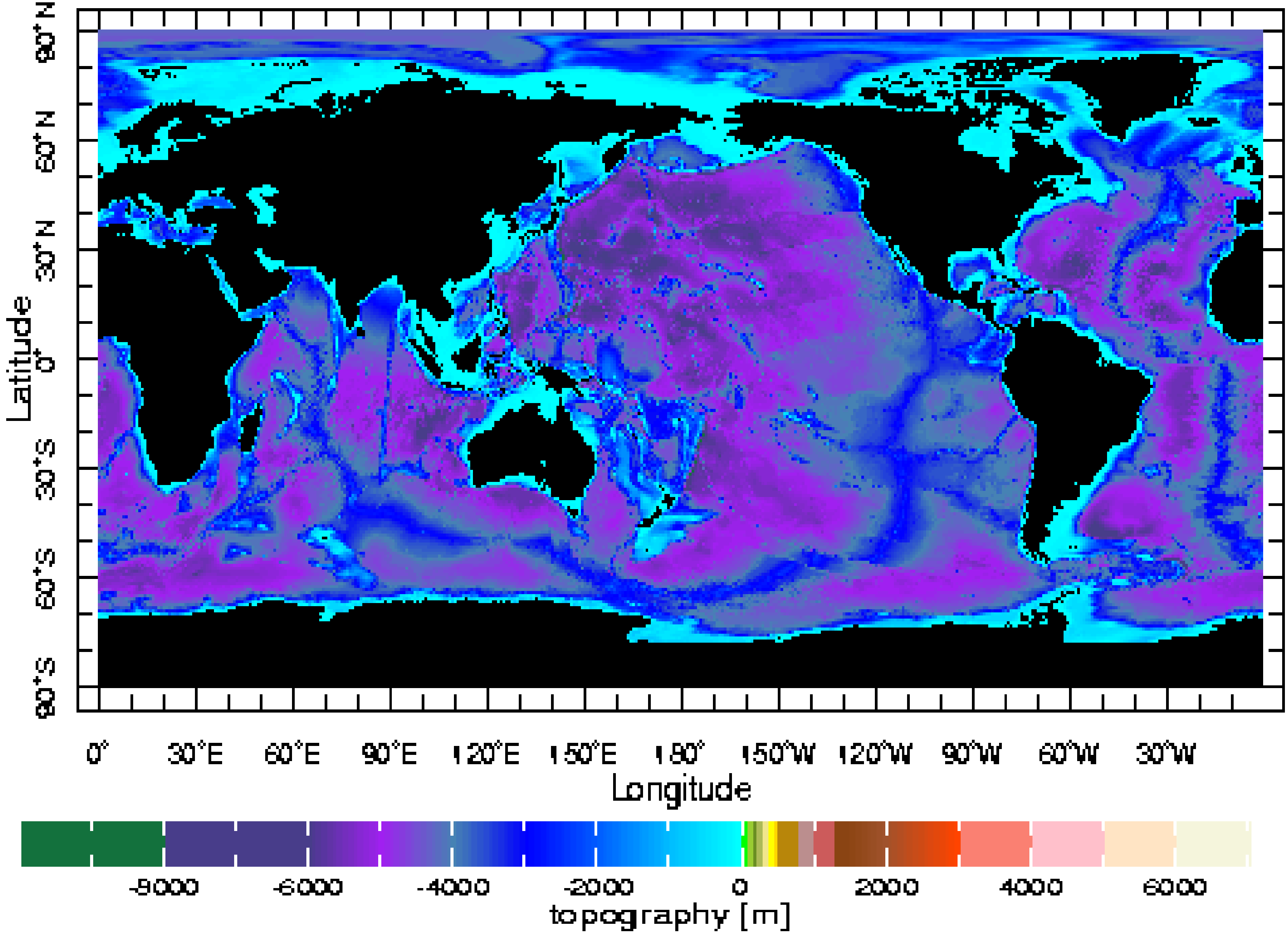
Major constituents of seawater

S=35

Constituent	$g\ kg^{-1}$
Cations	
Sodium	10.77
Magnesium	1.30
Calcium	0.412
Potassium	0.399
Strontium	0.008
Anions	
Cloride	19.34
Sulphate	2.71
Bromide	0.067
Carbon	
Inorganic carbon	0.023 (pH 8.4) - 0.027 (pH 7.8)

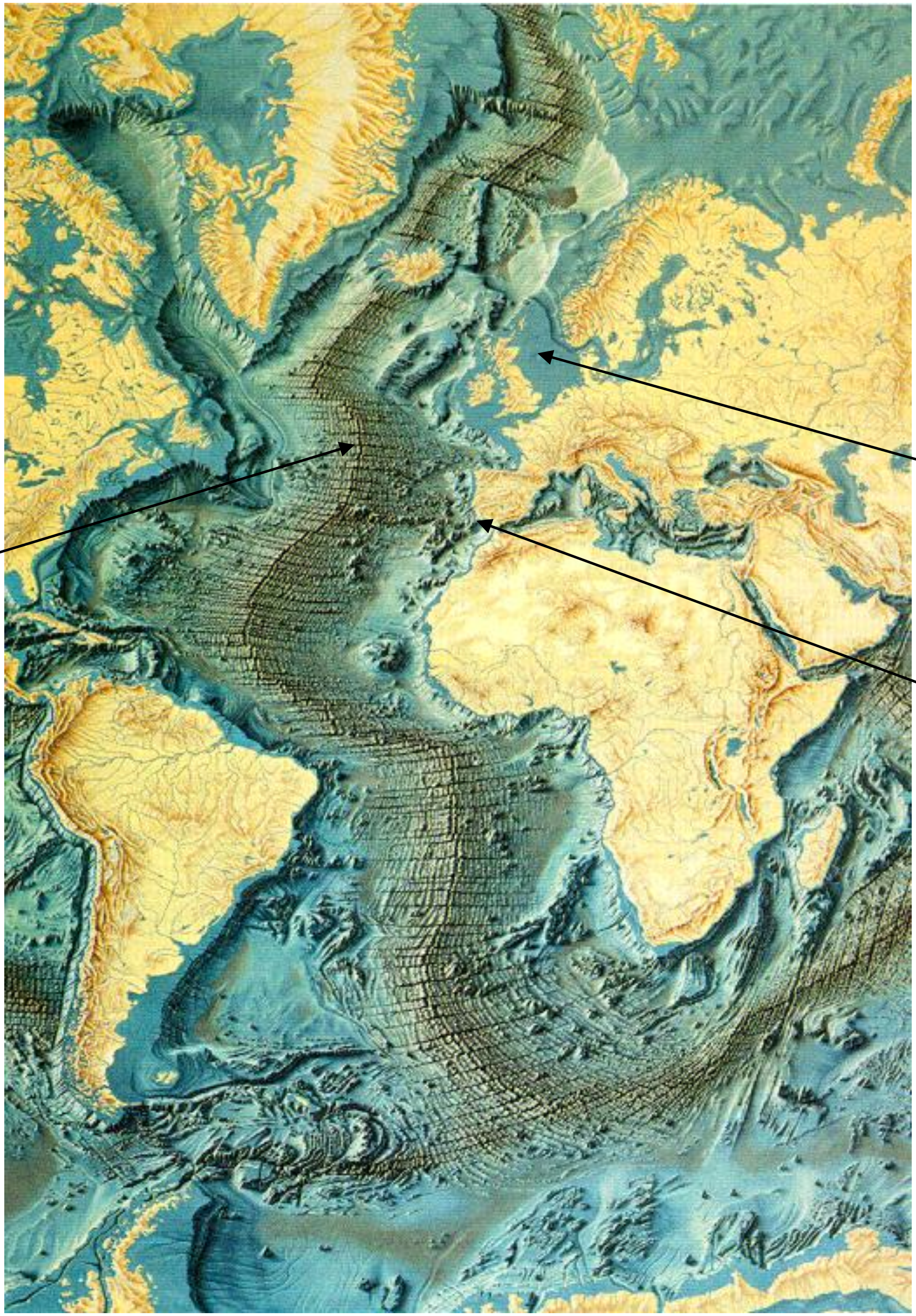
Ocean salinity varies very little, and the proportions among elements are remarkably constant.

World ocean bathymetry - NOAA



Average depth of 4000m, narrow upper layer where primary production occurs.

Atlantic Ocean Bathymetry

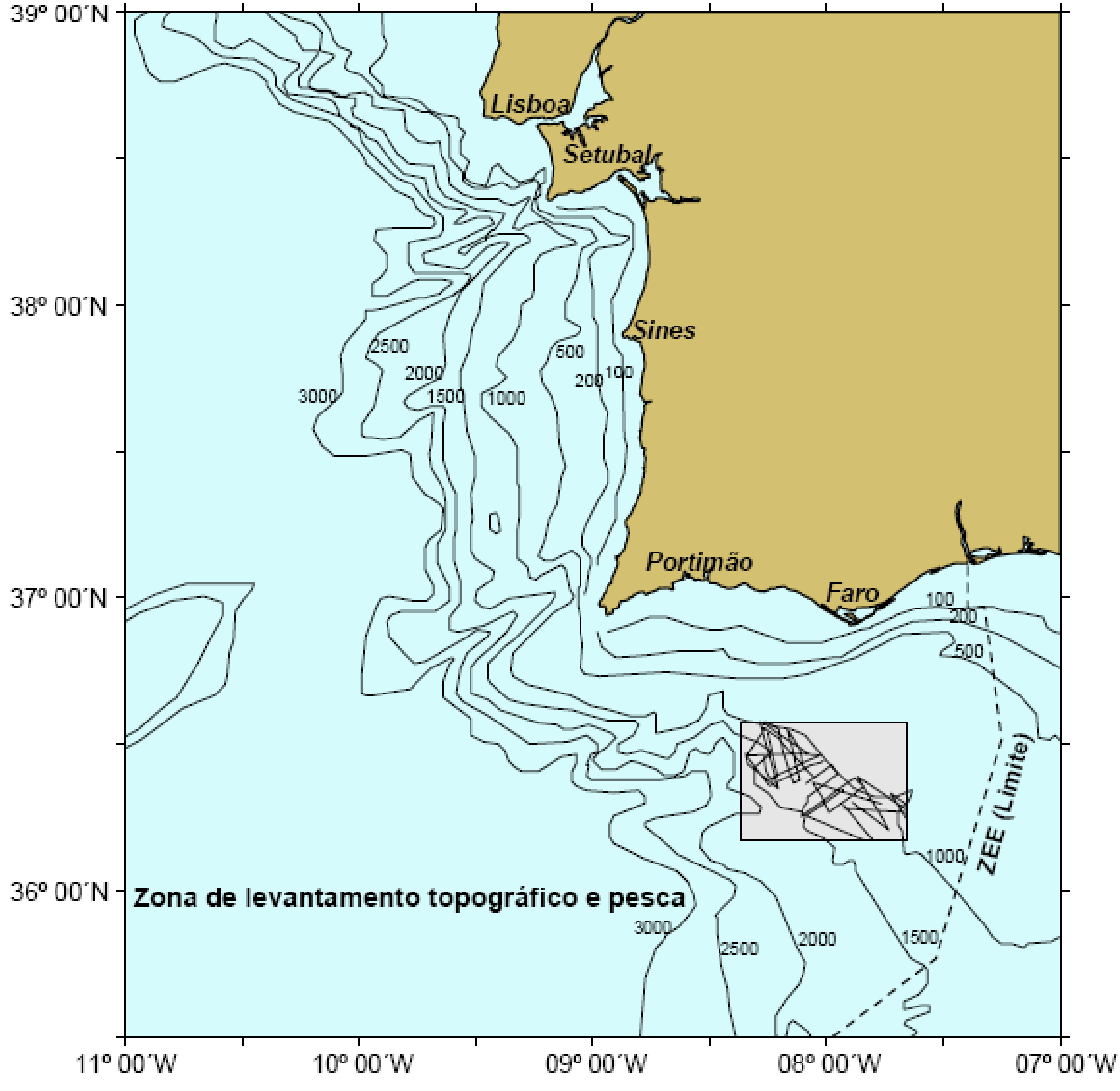


All expected morphology features are represented.

Atlantic Ocean - bathymetry

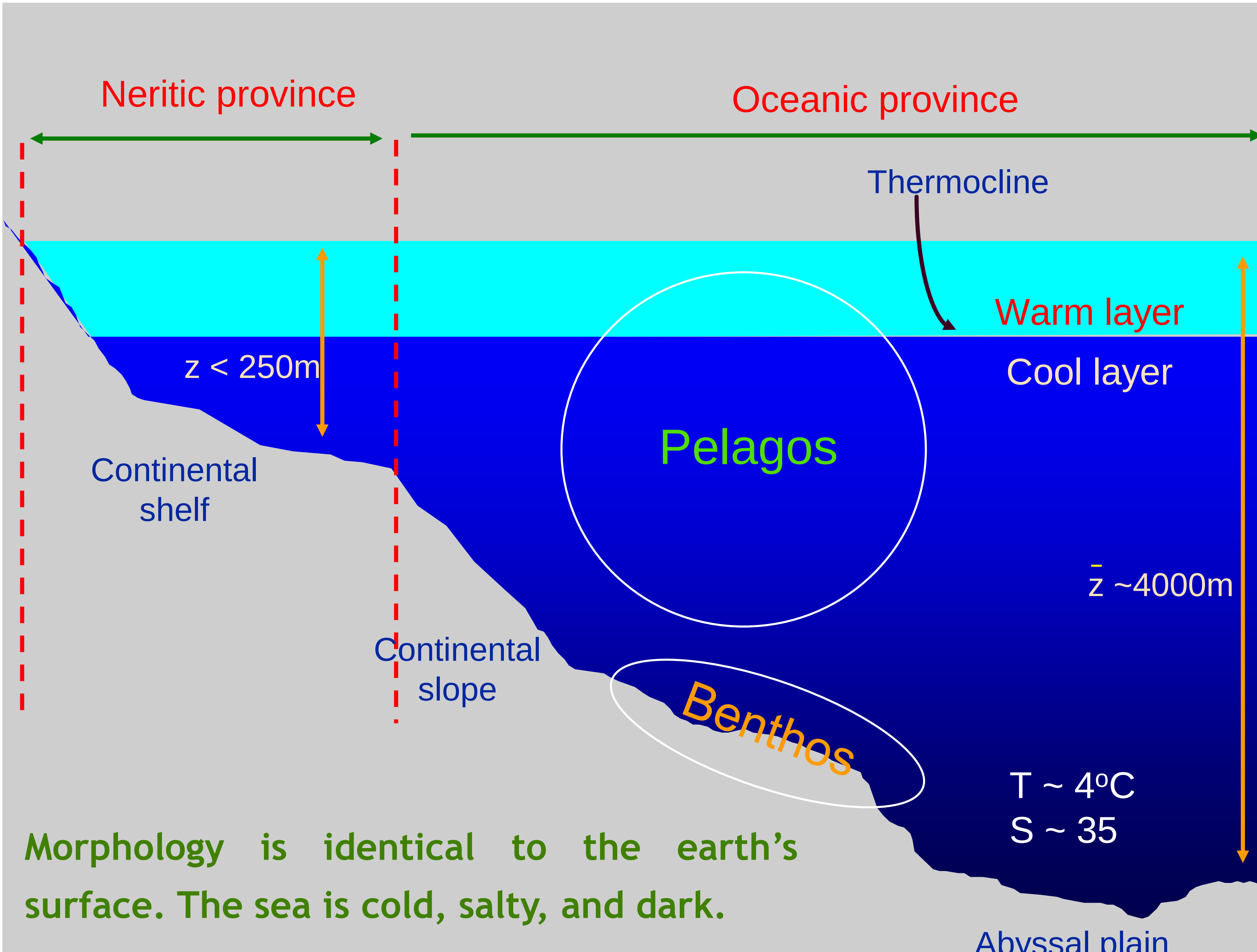
Iberian Atlantic - bathymetry

Detail of the Setubal canyon



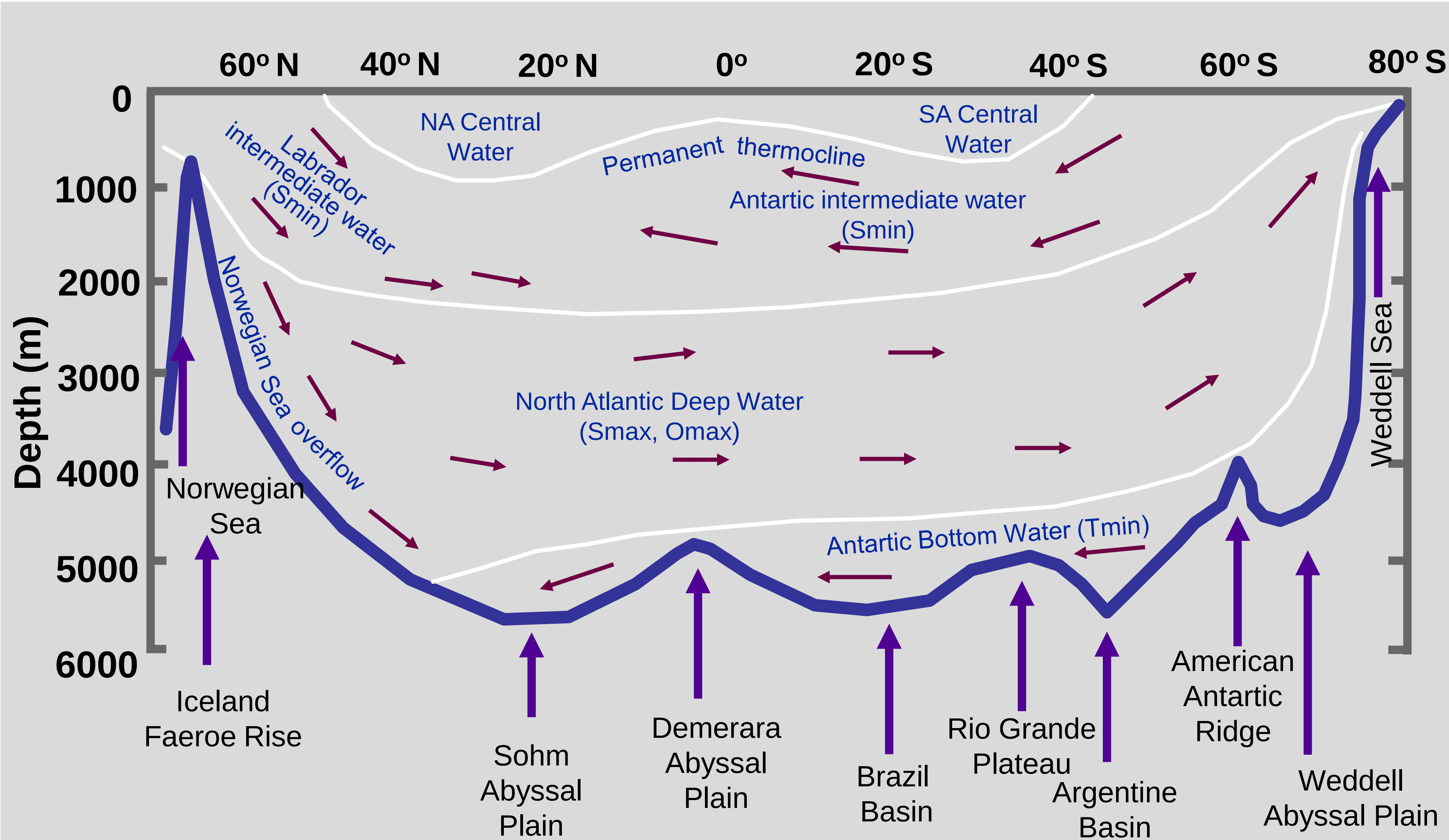
Over 2000 m depth very near the coast – the maximum depth of the southern North Sea is about 100 m.

General features of the ocean



Morphology is identical to the earth's surface. The sea is cold, salty, and dark.

General sub-surface circulation of the World Ocean



Adapted from Dietrich et al., 1980.

Coriolis effect

- **Coriolis parameter = $2\Omega \sin \phi$**

Where:

Ω = rate of angular rotation of the earth

ϕ = latitude

- **Coriolis acceleration = $2\Omega v \sin \phi$**

Where:

v = velocity

F=ma therefore:

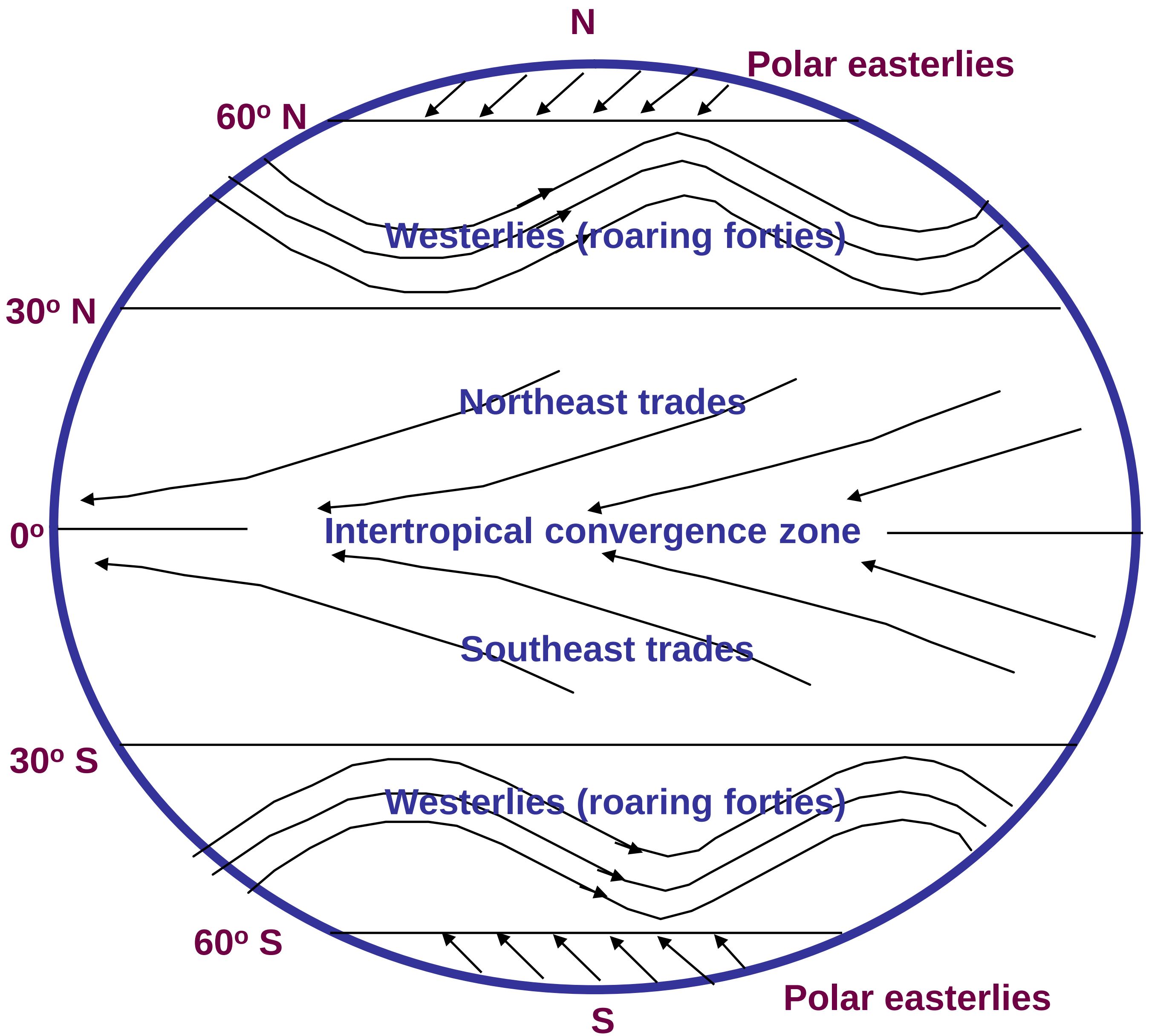
- **Coriolis force = $2\Omega m v \sin \phi$**

Where:

m = mass

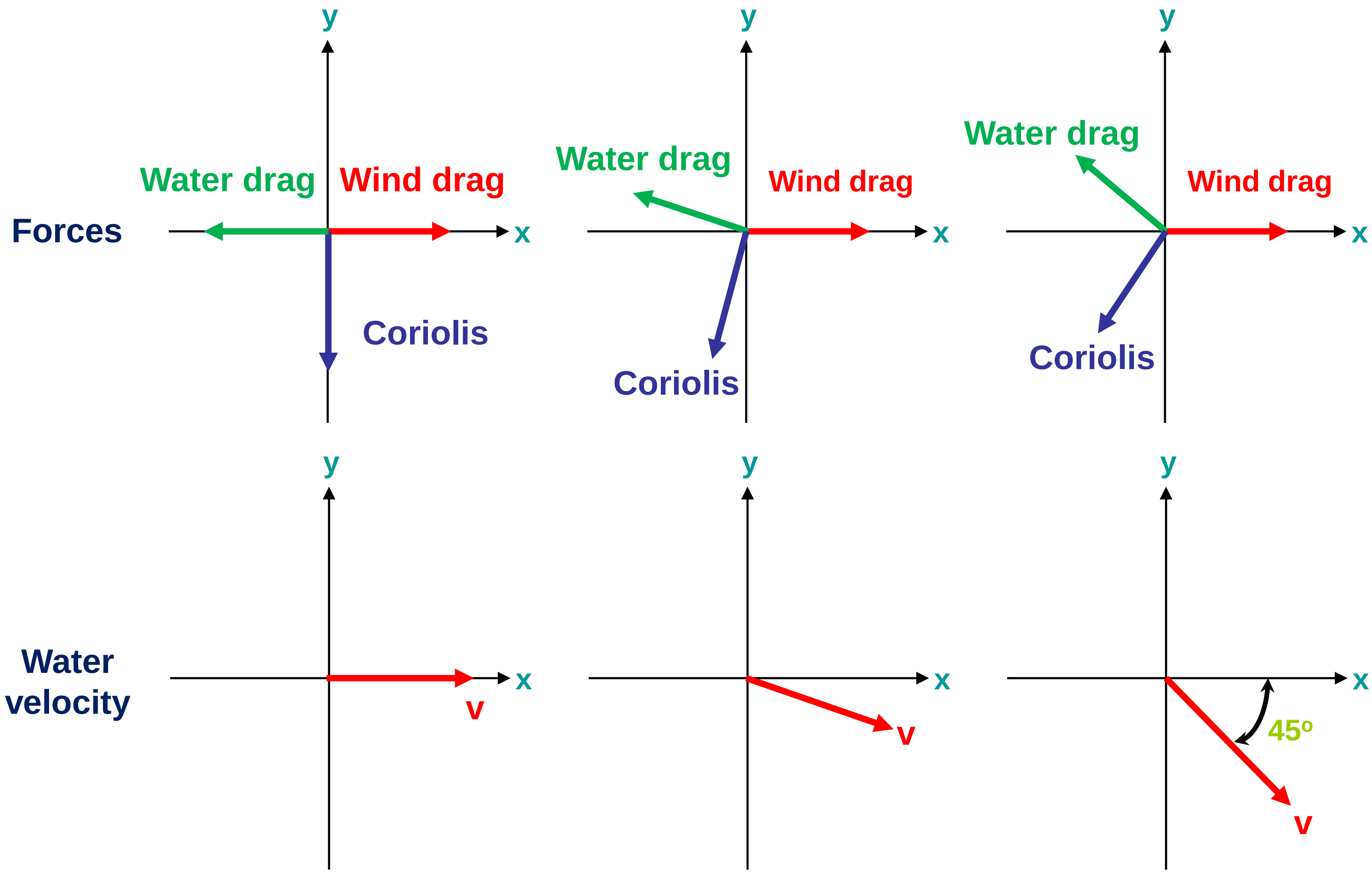
Force is most important at the poles and zero at the equator.

Major wind systems of the world



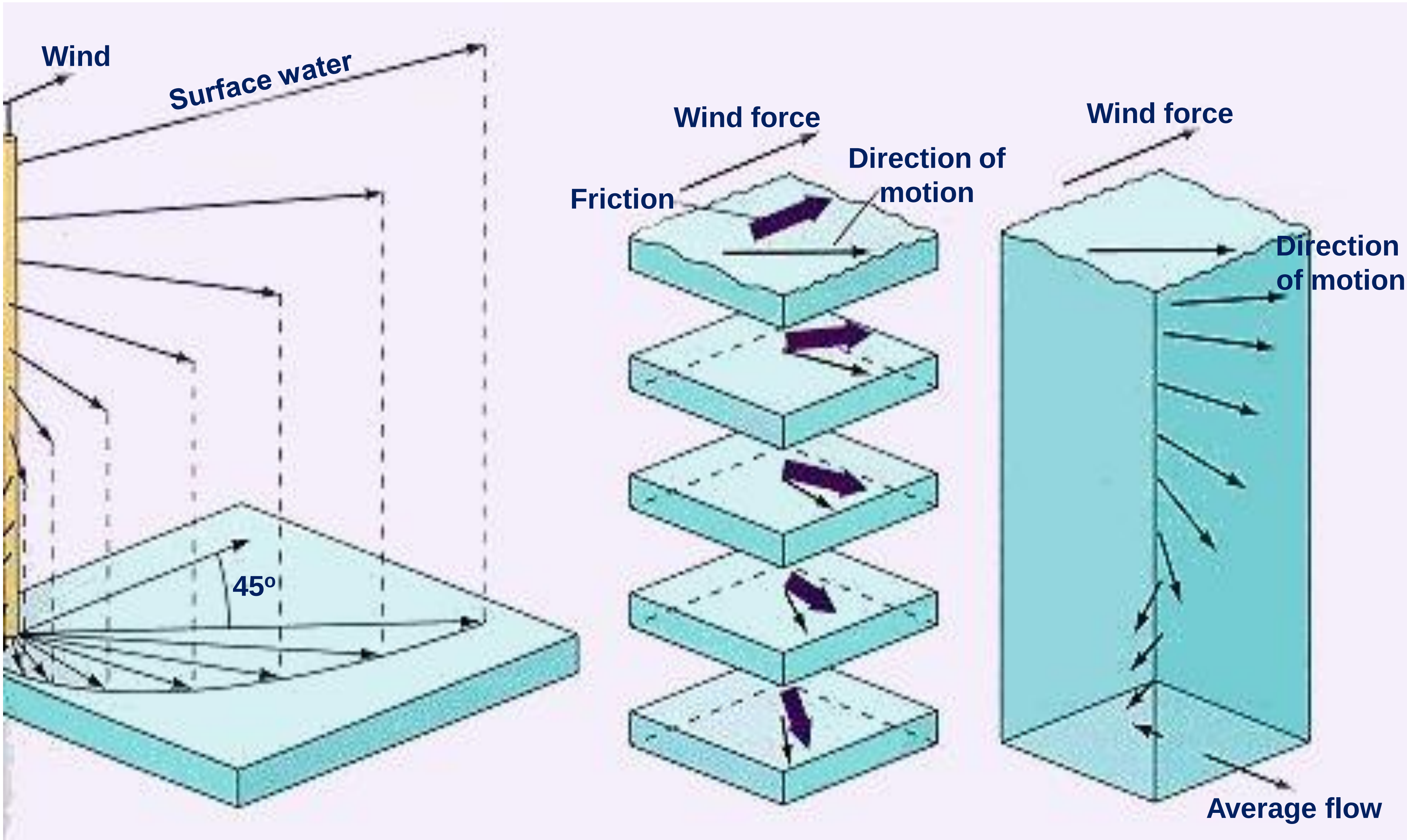
Winds drive surface circulation, density drives deep water (thermohaline).

Wind-driven surface currents



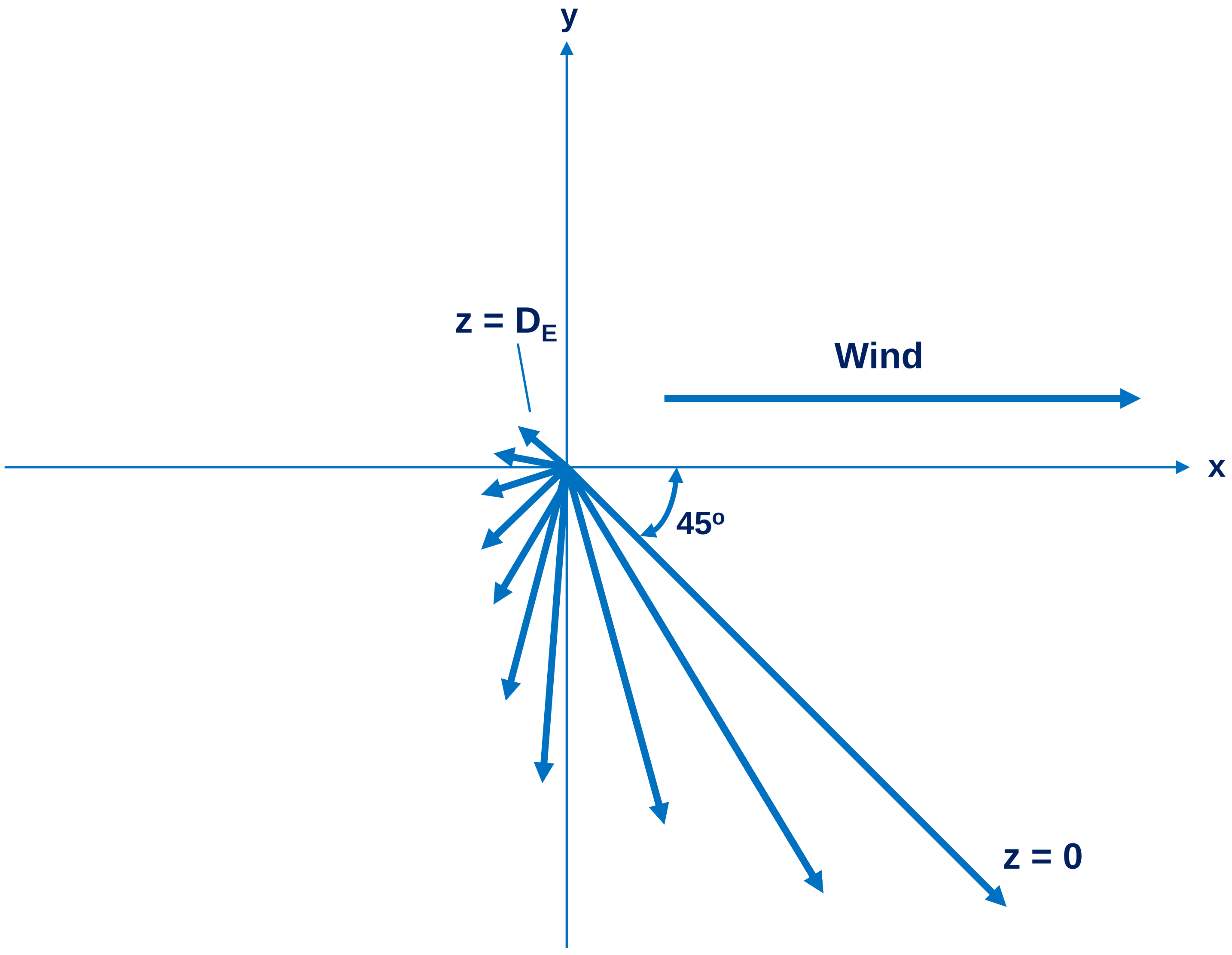
Equilibrium flow at 45° to the wind acting on the water surface.

Eckman spiral - schematic representation



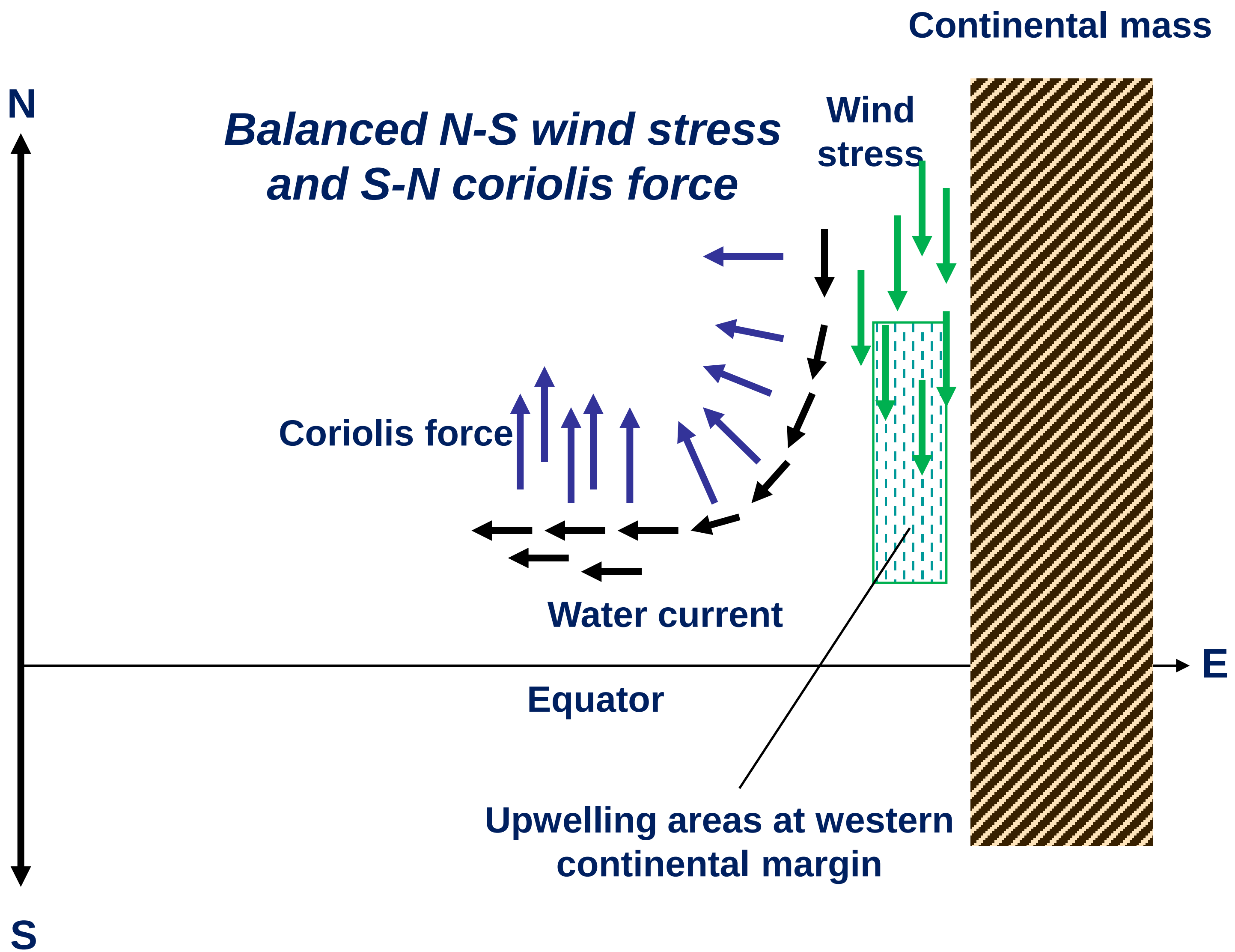
Discretisation of vertical water masses illustrates the spiral effect.

Eckman spiral - schematic representation



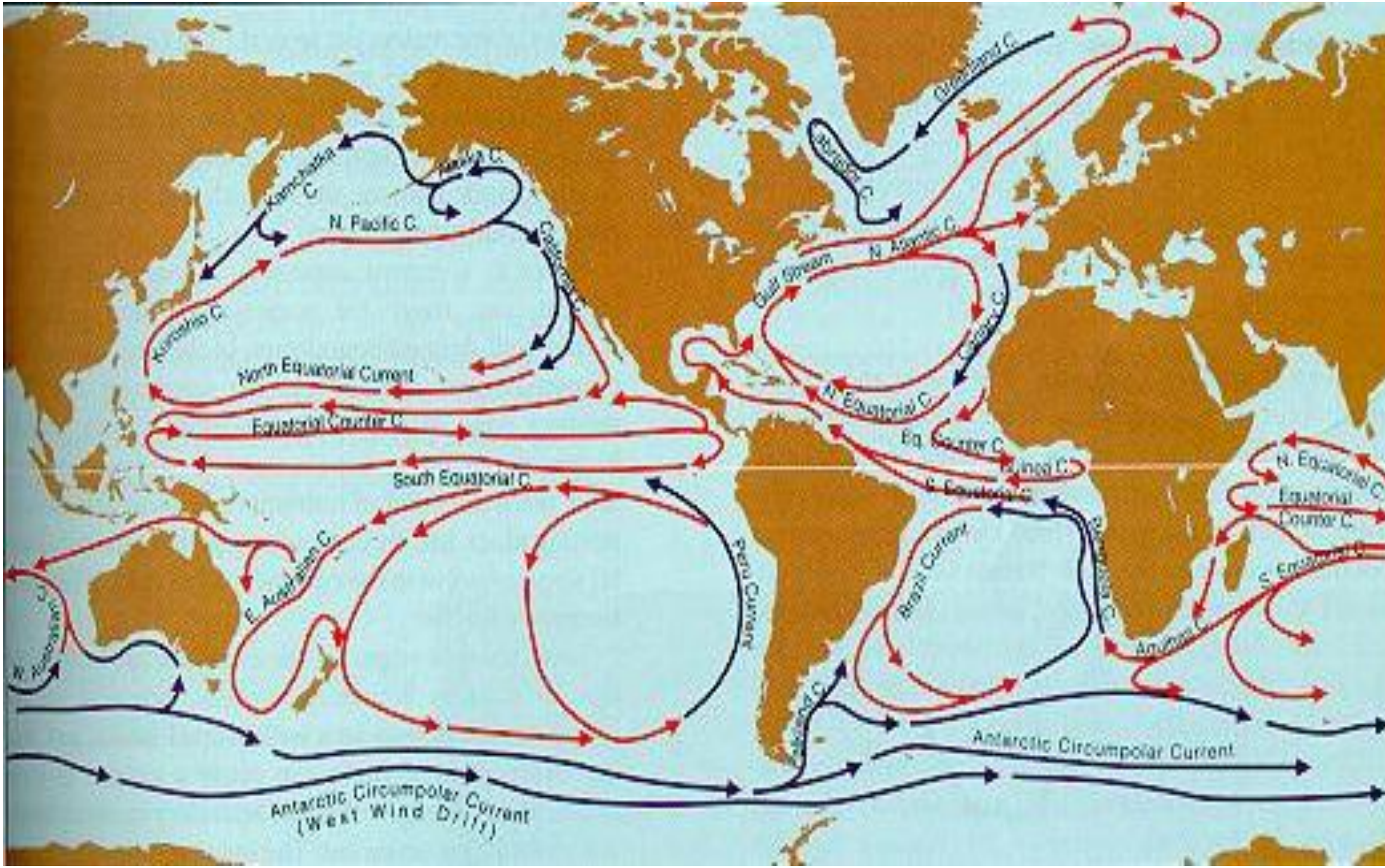
Current speed in the last layer is opposite to surface, and much slower.

Geostrophic balance



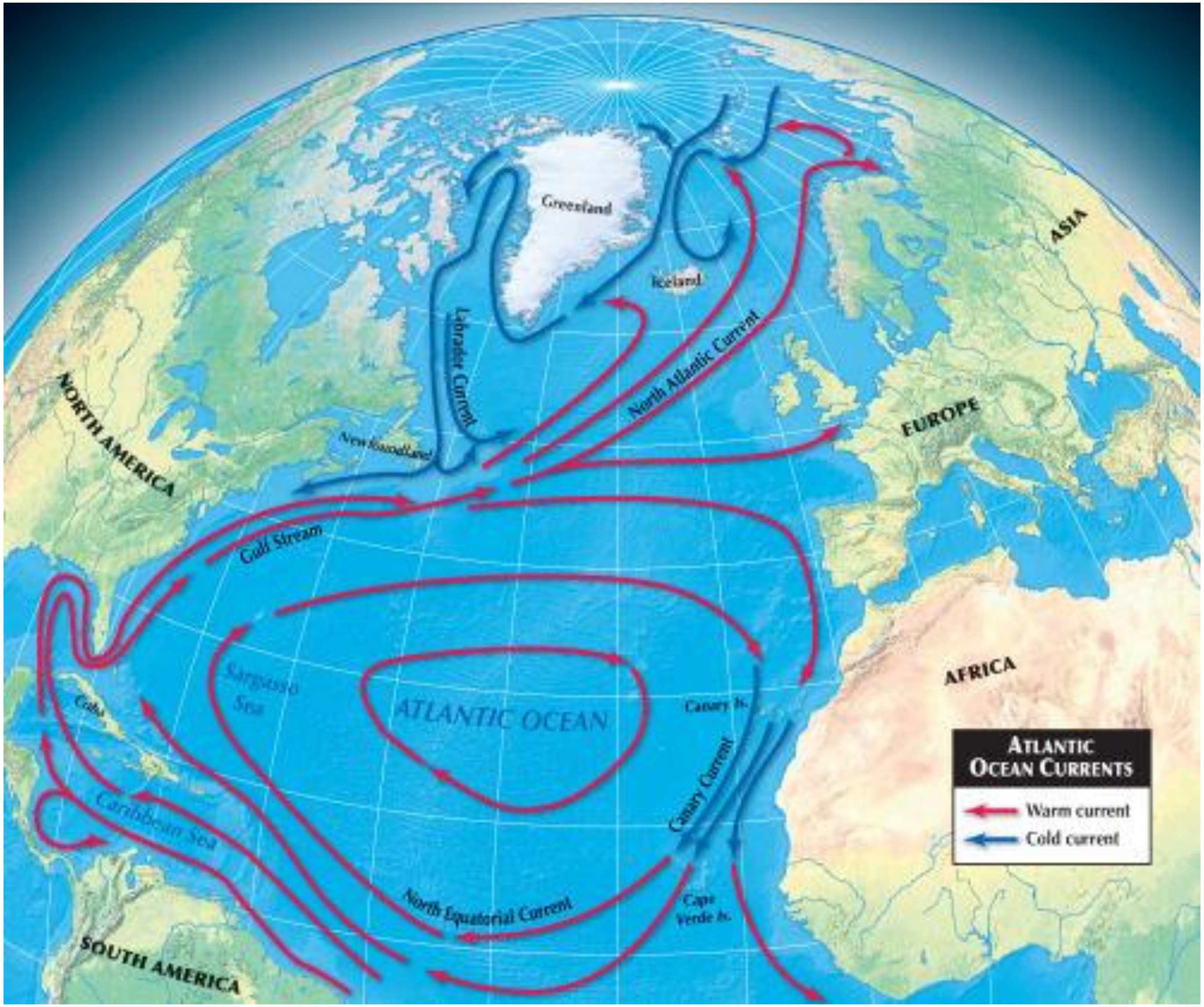
A model for the anticyclonic gyres in the surface circulation of the ocean.

Surface currents in the global ocean



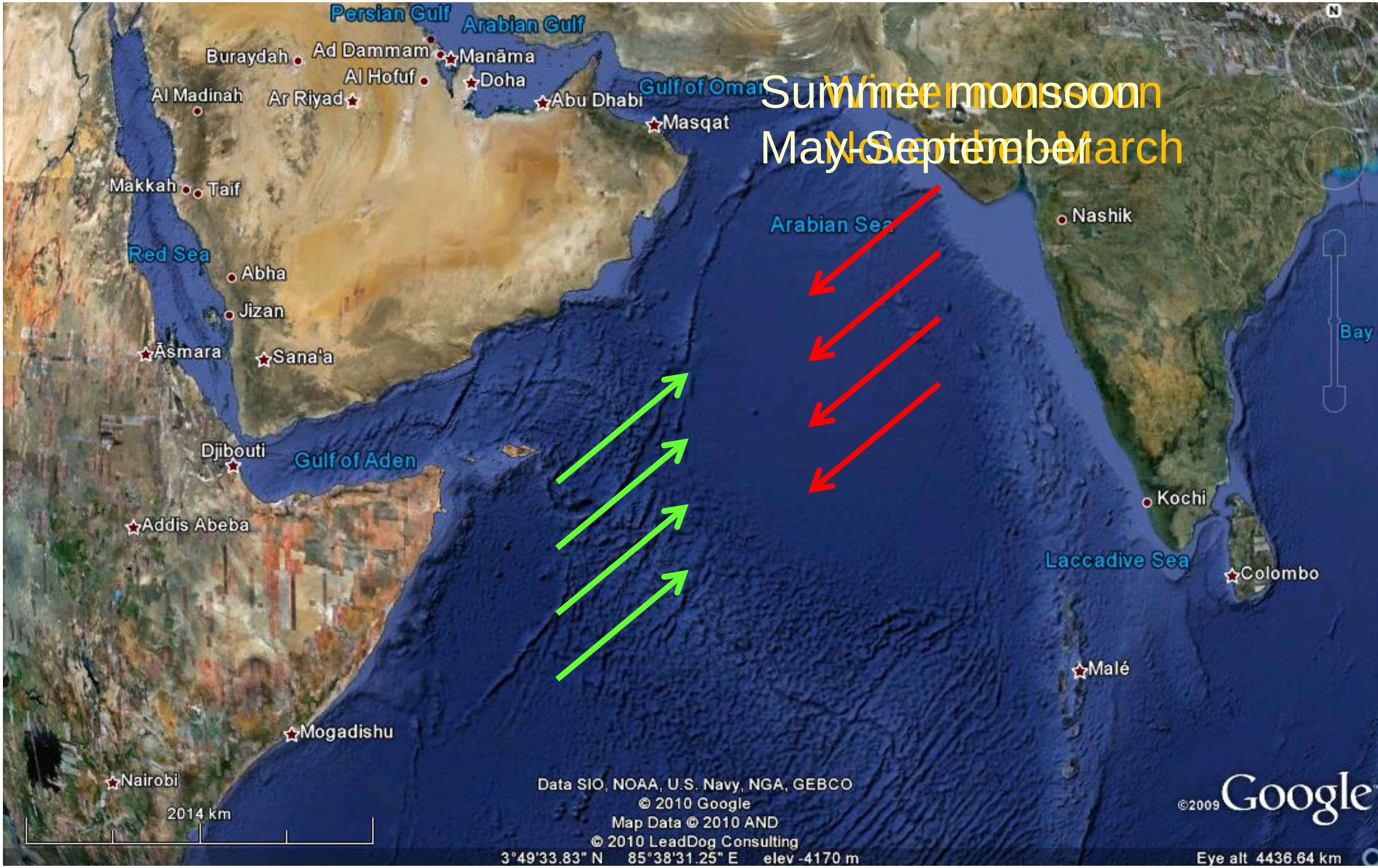
Cold current   Warm current

Ocean currents – North Atlantic



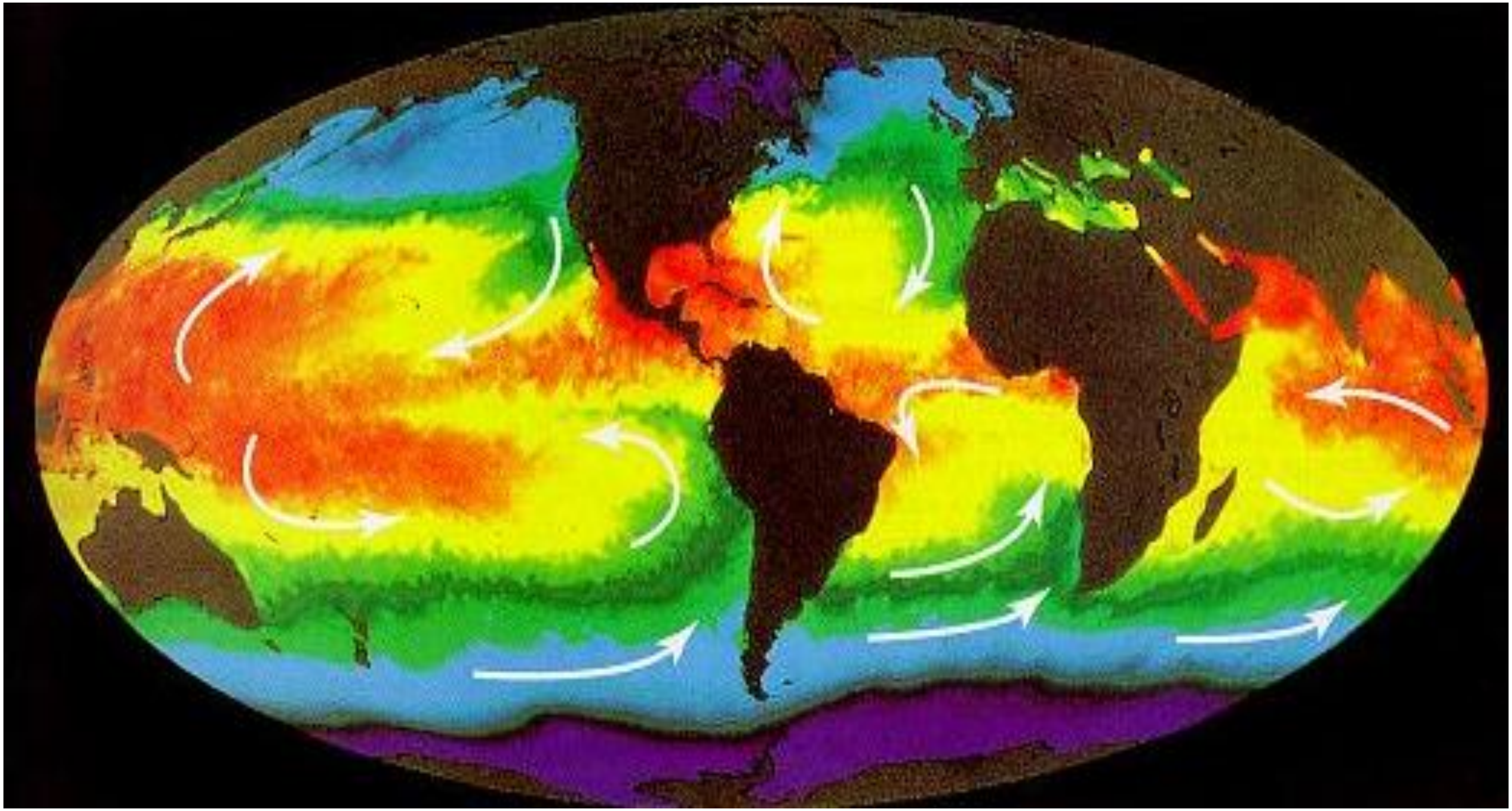
http://www.spatialgraphics.com/educ.htm

The Mausim



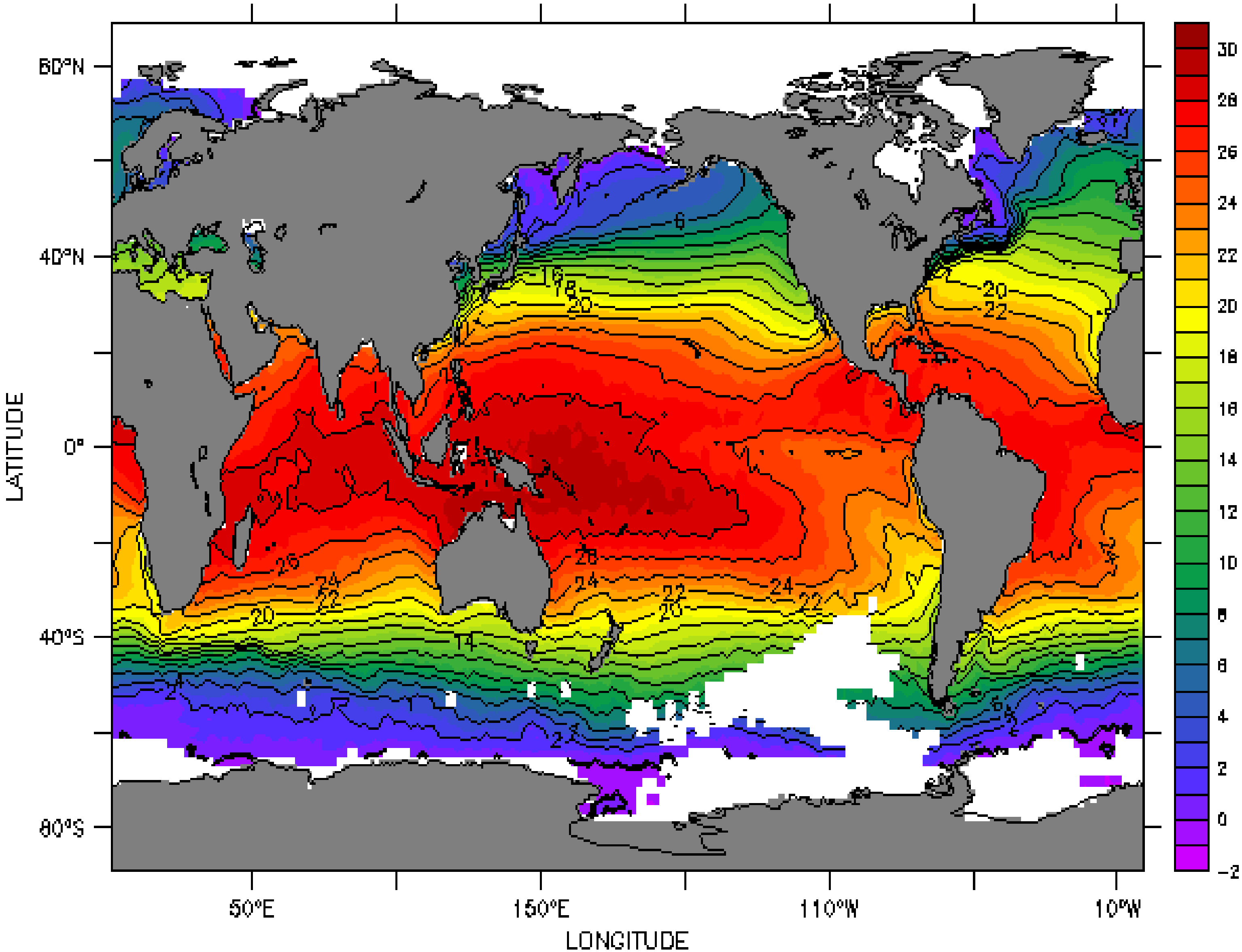
Summer monsoon
May-September
Winter monsoon
November-March
Persian Gulf
Arabian Gulf
Buraydah
Ad Dammam
Manāma
Al Hofuf
Doha
Al Madinah
Ar Riyad
Abu Dhabi
Gulf of Oman
Masqat
Makkah
Taif
Red Sea
Abha
Jizan
Āsmara
Sana'a
Arabian Sea
Nashik
Bay o
Djibouti
Gulf of Aden
Addis Abeba
Kochi
Laccadive Sea
Colombo
Malé
Mogadishu
Nairobi
2014 km
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2010 Google
Map Data © 2010 AND
© 2010 LeadDog Consulting
3°49'33.83" N 85°38'31.25" E elev -4170 m
©2009 Google
Eye alt 4436.64 km

Global ocean - surface gyres and temperatures



Wind-driven circulation. Clockwise (anticyclonic) gyres in the northern hemisphere, cyclonic gyres in the southern hemisphere.

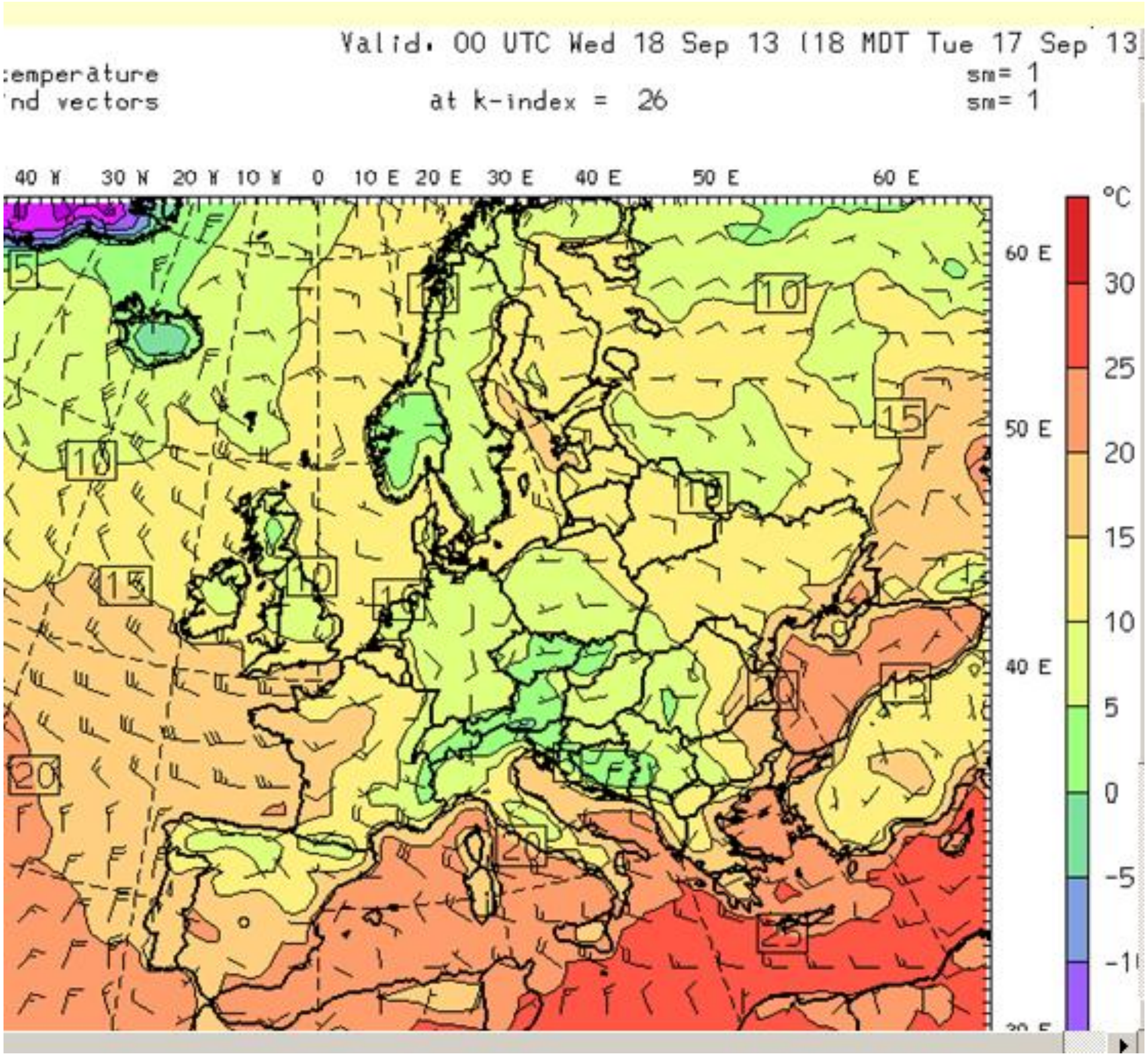
Sea surface temperature (NOAA)



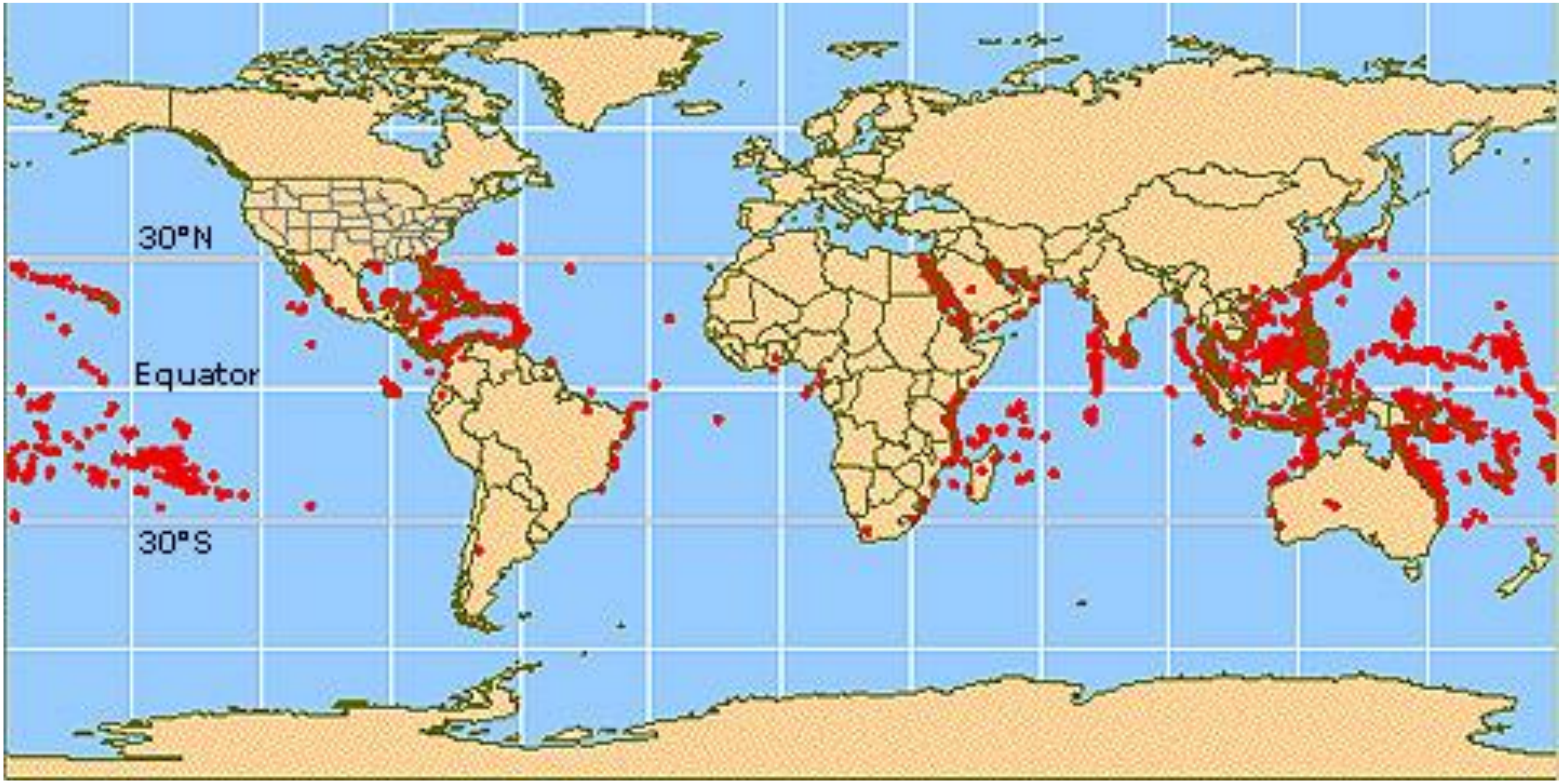
Data in °C - COADS monthly climatology dataset (1946-1989)

The eastern part of the Atlantic and Pacific is colder than the west.

Sea surface temperature from the NCAR/MMM online model



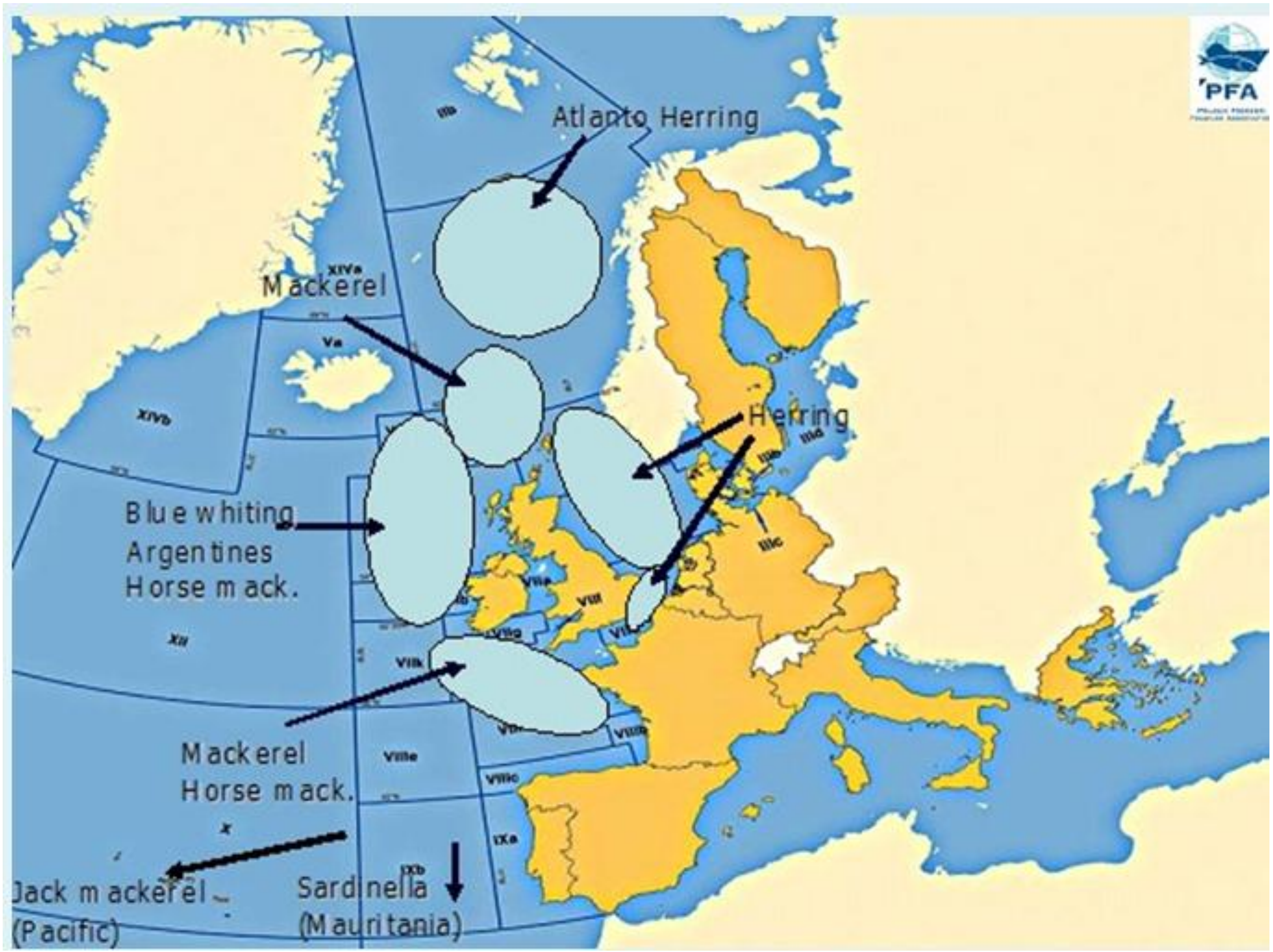
Distribution of corals in the world ocean



http://oceanservice.noaa.gov/education/kits/corals/media/supp_coral05a.html

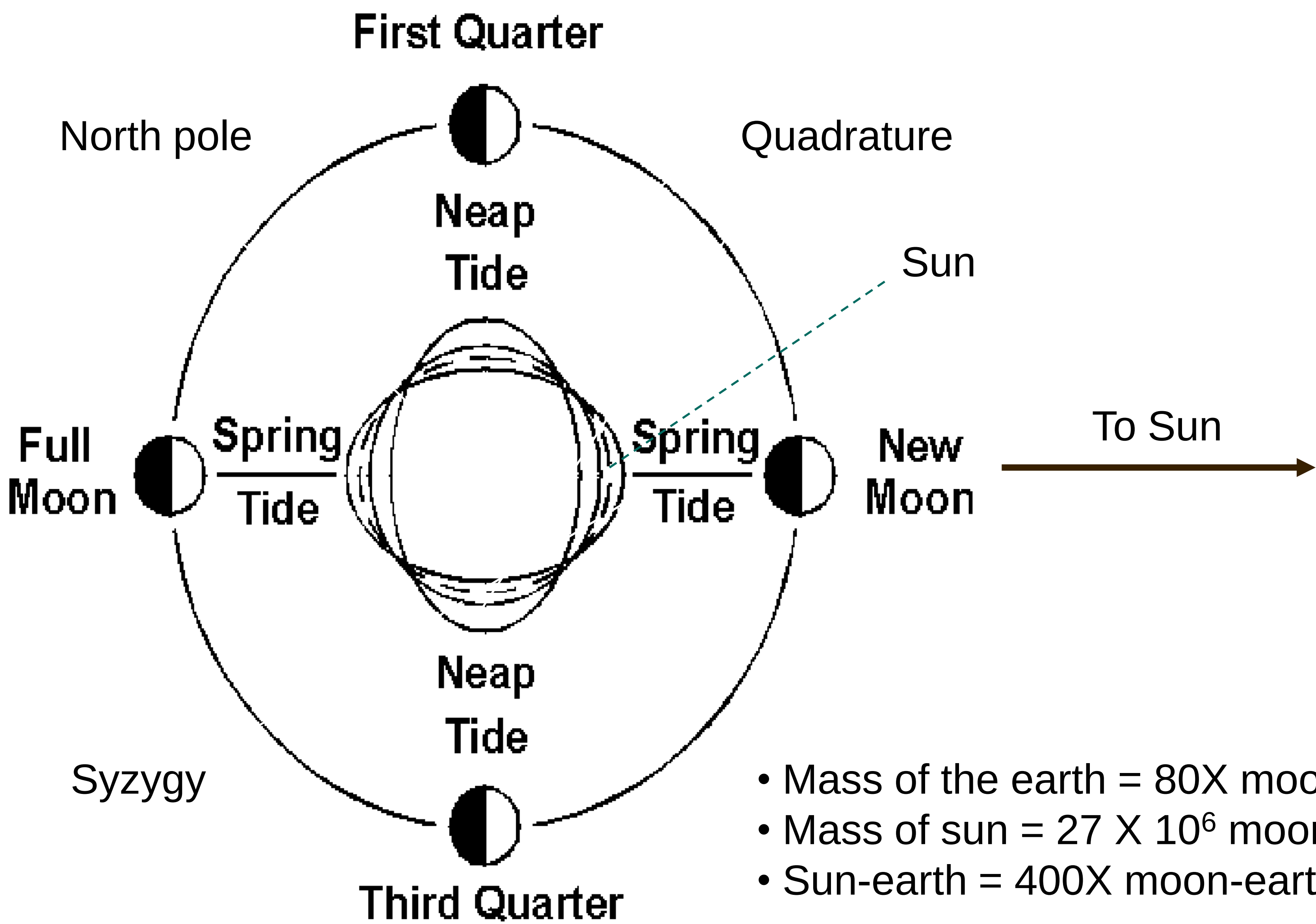
Warm water corals are present on the western sides of the world oceans, due to the surface temperature distribution. This is regulated by wind-driven ocean circulation patterns.

Pelagic fisheries in the world ocean



Pelagic fisheries (e.g. sardine, anchovy, mackerel) are mainly on the eastern sides of the world oceans, due to the surface temperature distribution. This is regulated by wind-driven ocean circulation patterns.

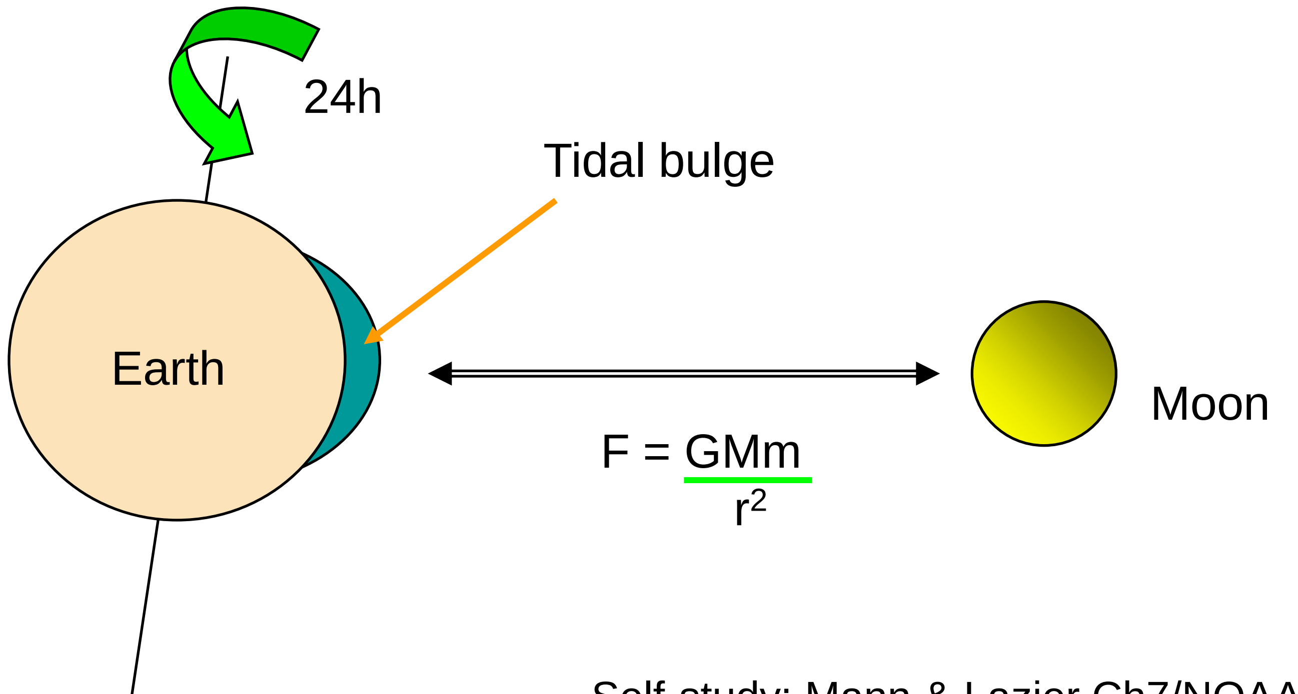
Tides and tide generating forces



- Mass of the earth = 80X moon
- Mass of sun = 27 X 10^6 moon
- Sun-earth = 400X moon-earth

The sun is much larger than the moon, but the moon is much closer.

Tides and tide generating forces
Model for one daily tide

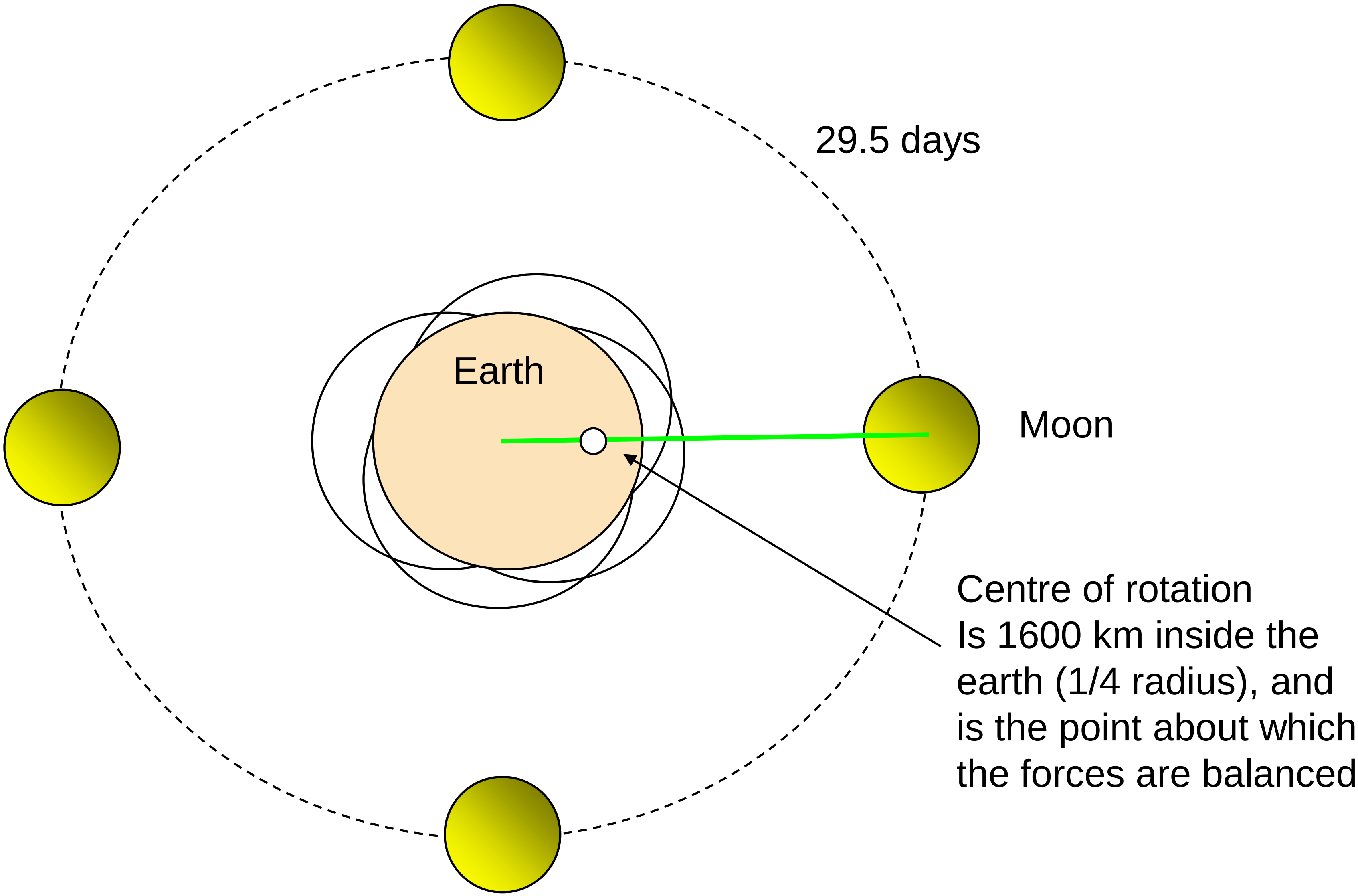


$$F = \frac{GMm}{r^2}$$

Self-study: Mann & Lazier Ch7/NOAA website

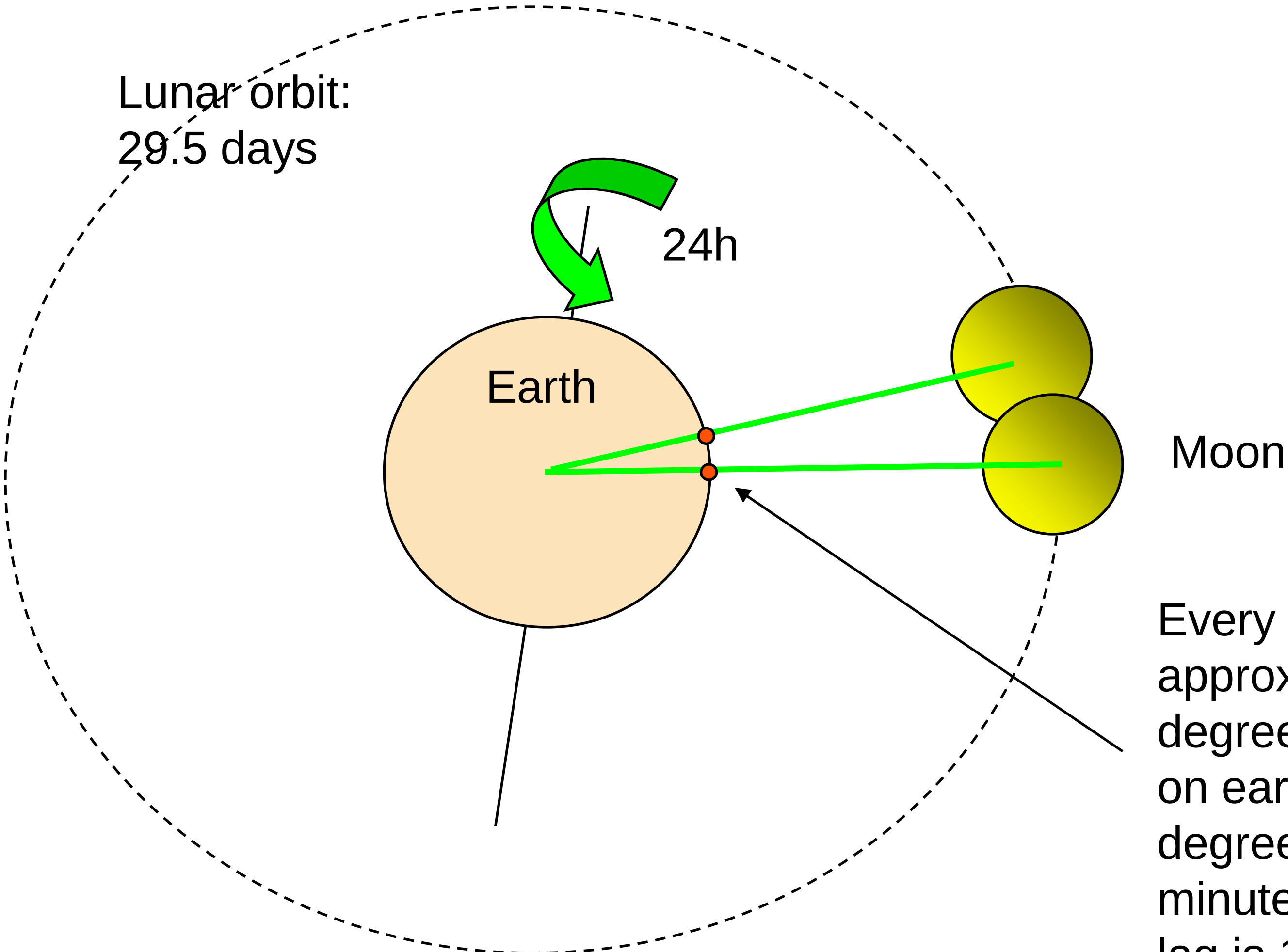
The model is based on the gravitational attraction between the moon and earth.

Tides and tide generating forces
Model for a semi-diurnal tide



The model is based on the gravitational attraction between the moon and earth.

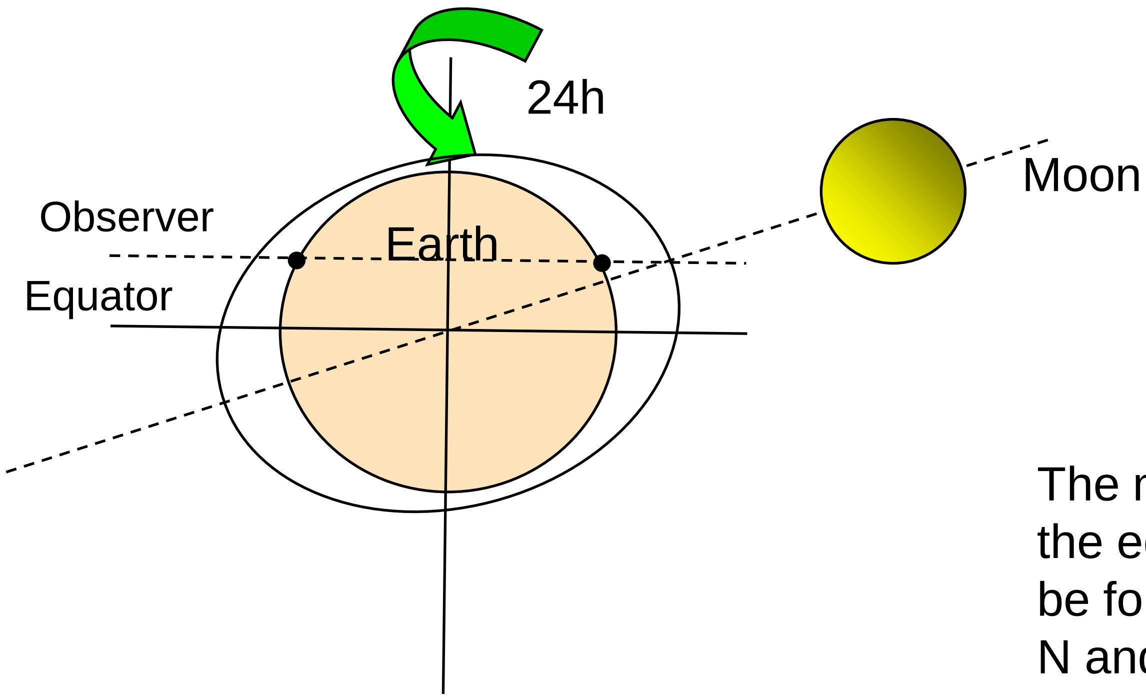
Tides and tide generating forces
Model for tidal delay



Every day the moon moves approximately 360/30 degrees, i.e. 12°. The time on earth equivalent to 1 degree is 24 * 60 / 360 = 4 minutes, therefore the time lag is 12 * 4 = 48 minutes

The semi-diurnal tide actually has a period of 12h 25m.

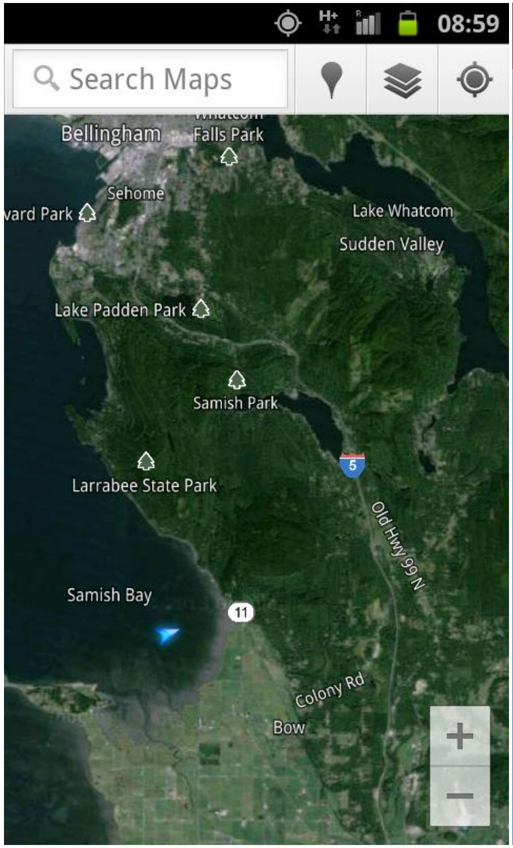
Tides and tide generating forces
Model for diurnal inequality

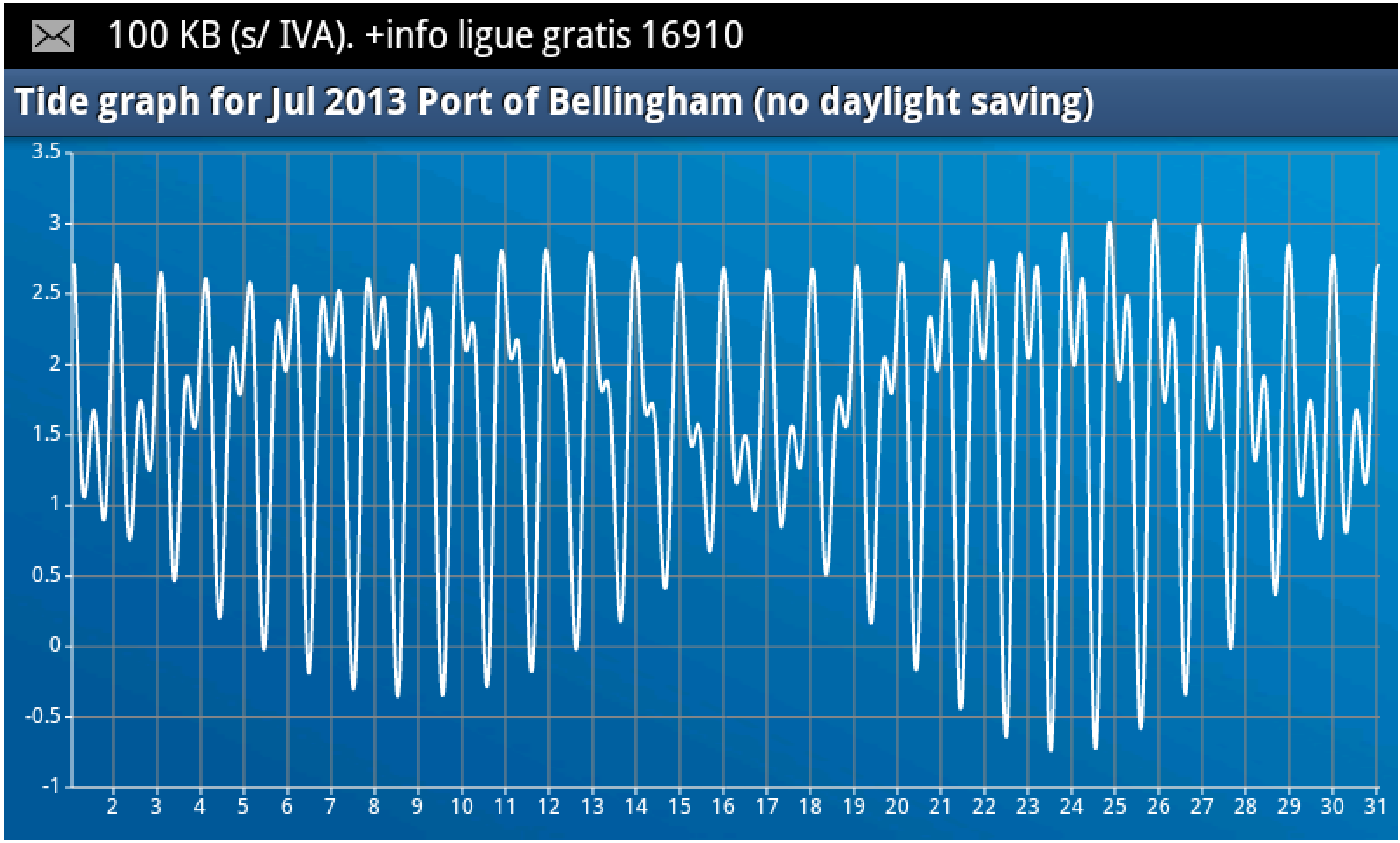


The moon is shown 25°N of the equator. The moon can be found at various angles N and S of the equator (up to 35°) depending on season and lunar cycle

In some parts of the world, there is a very pronounced diurnal inequality.

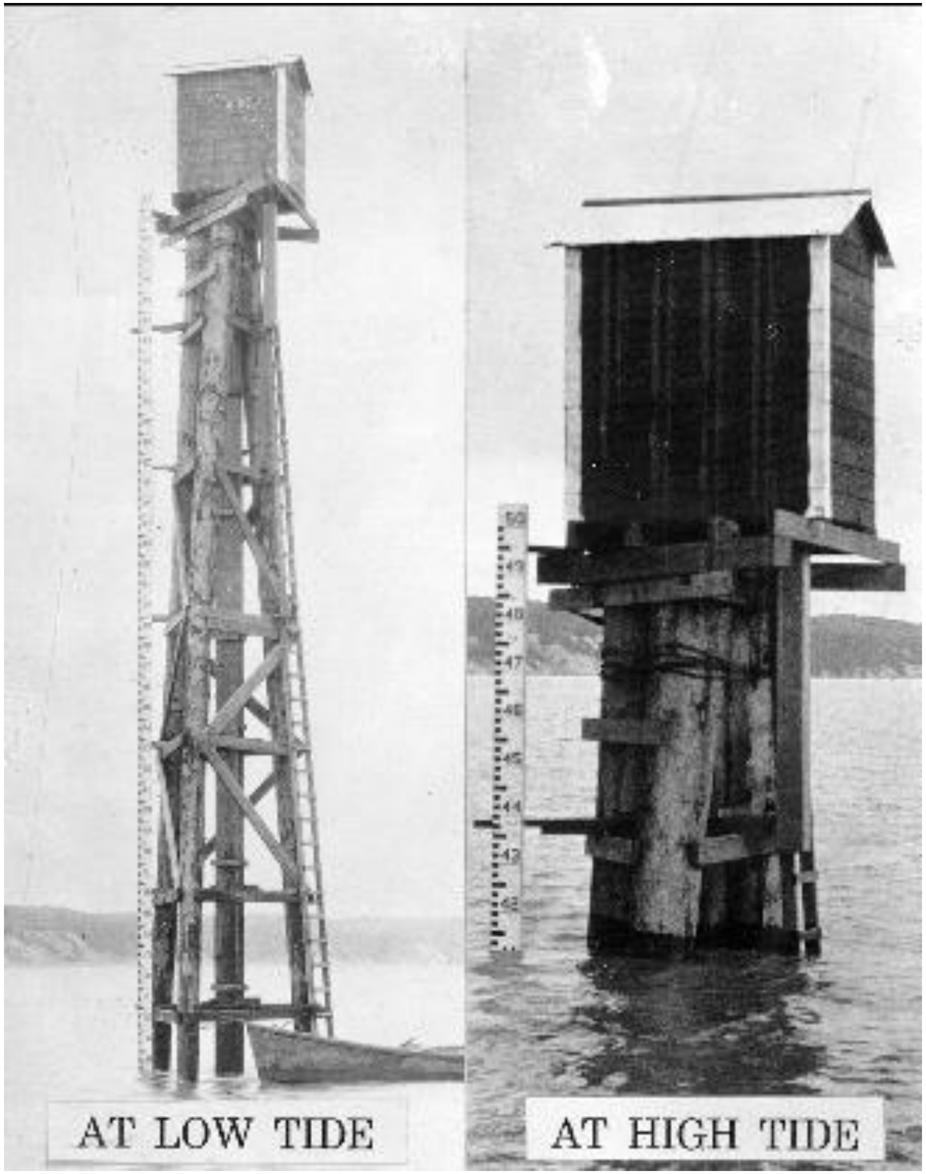
Samish Island, North Puget Sound
Diurnal tidal inequality

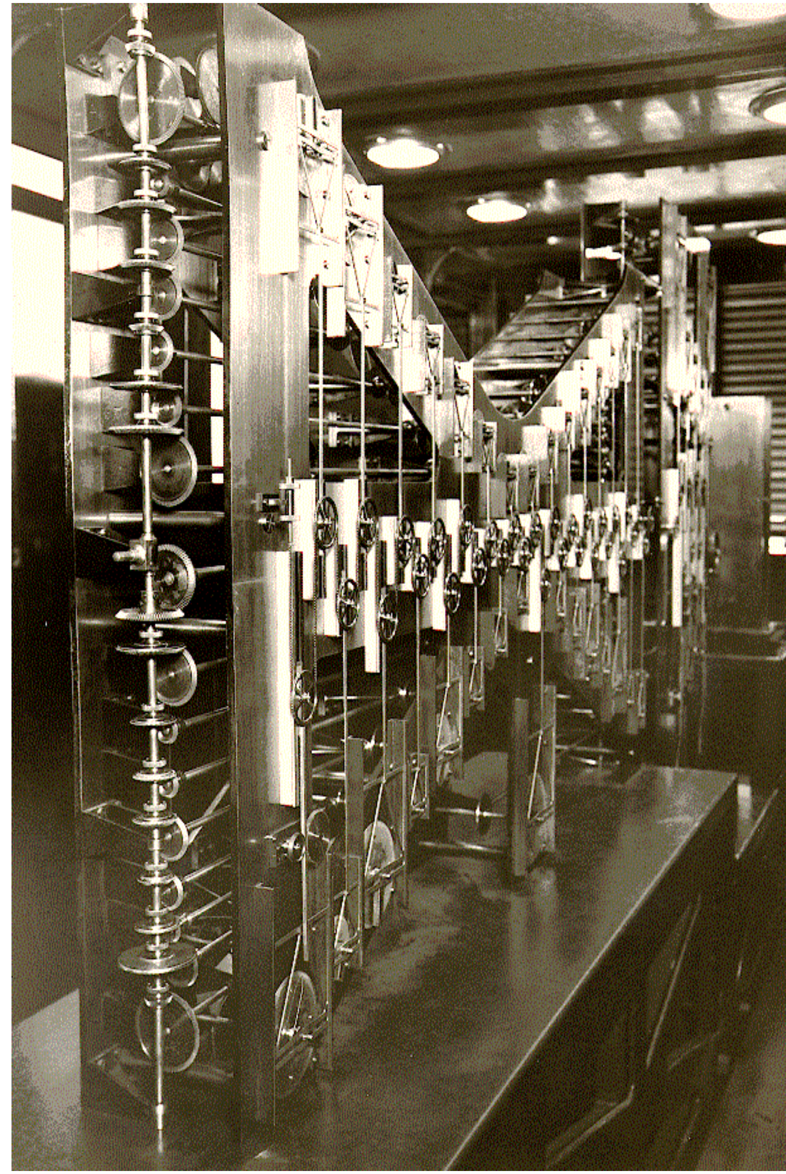




In winter, the good tides are at night. Bad news if you harvest clams.

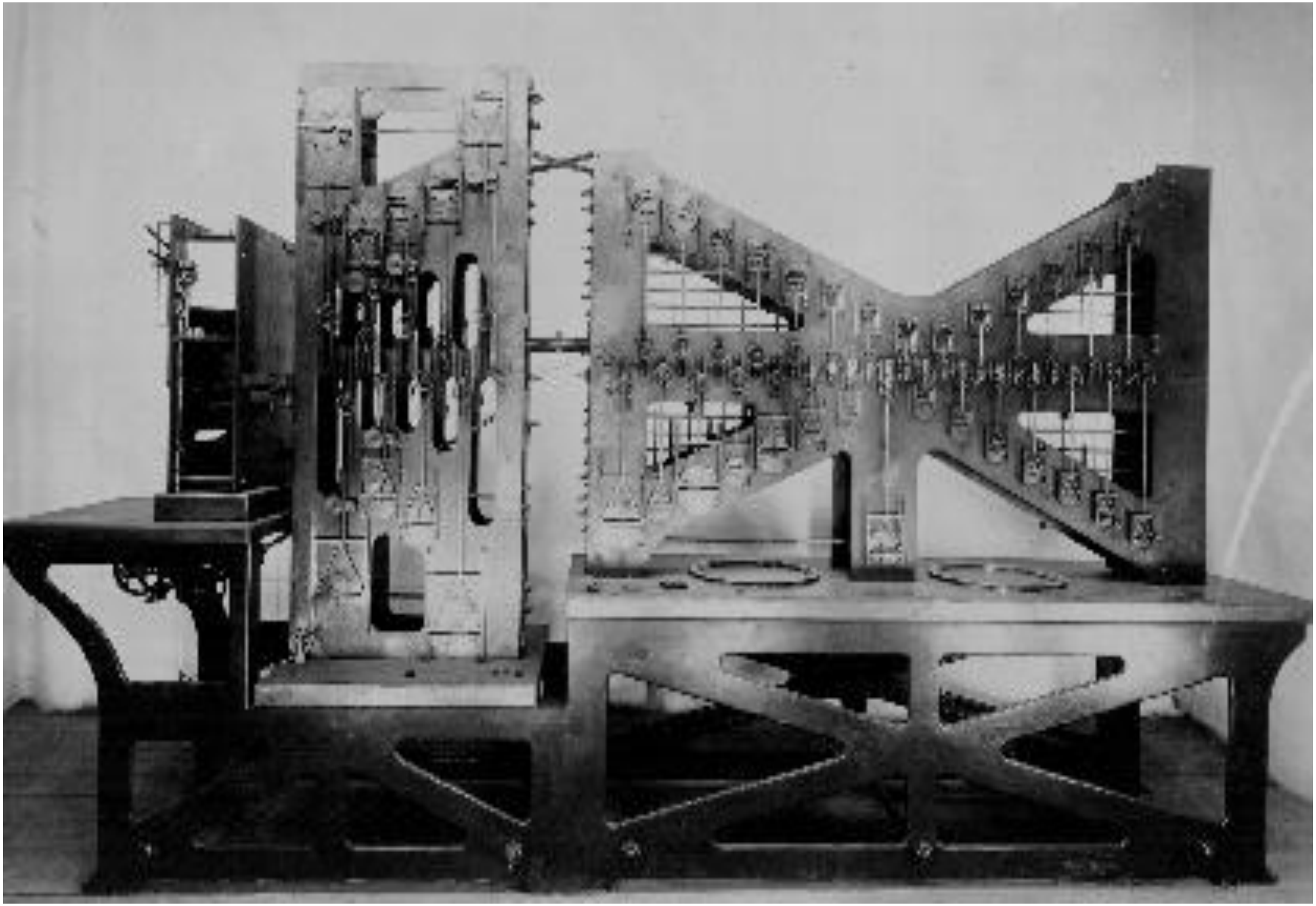
Early tide gauges and prediction machines





Left: tide gauge at Anchorage, Alaska; right: mechanical tide machine.

Mechanical tide prediction equipment



Today a smartphone replaces complicated mechanical machinery.

Tides in the real ocean

Types of constituents

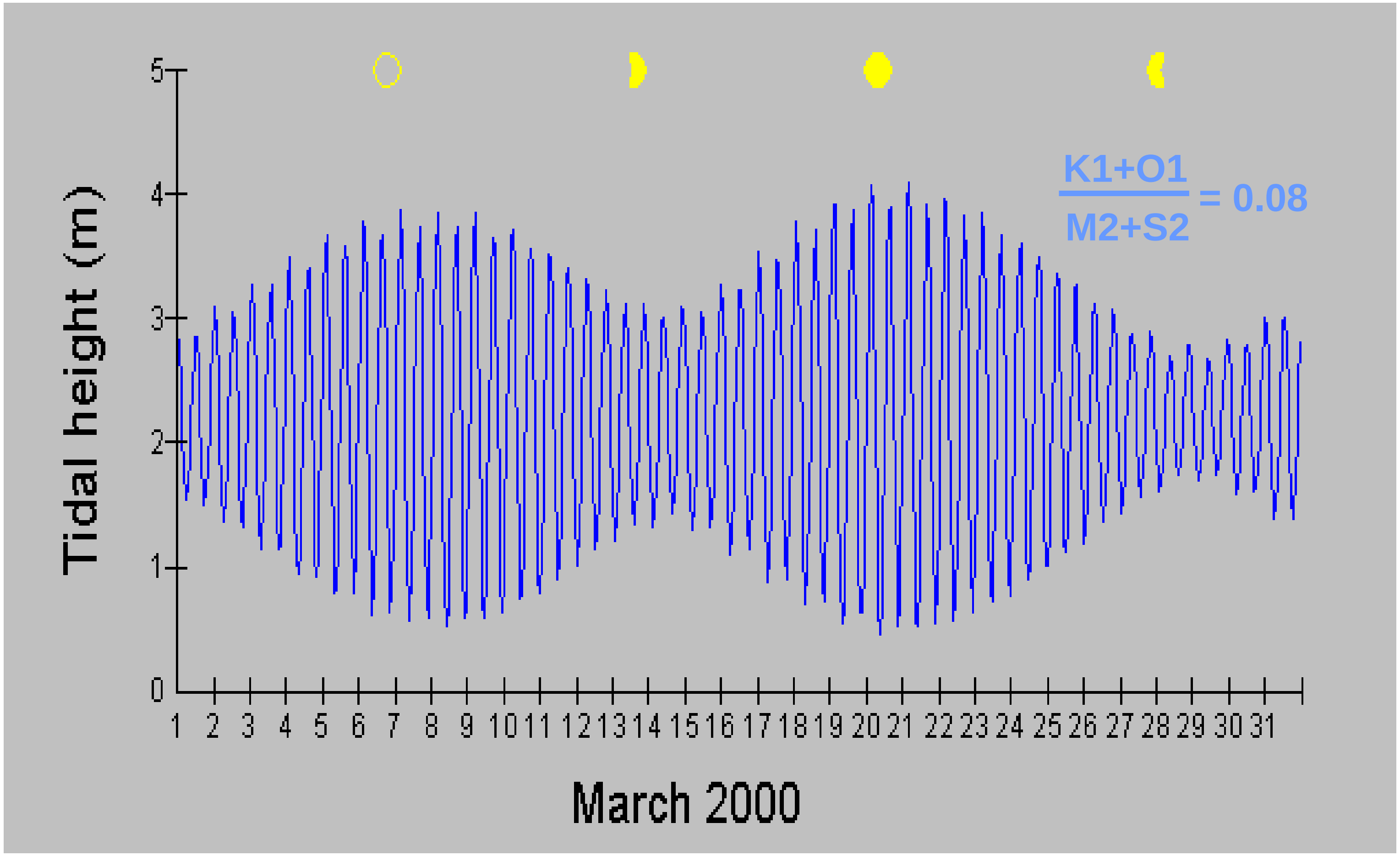
- Semi-diurnal
- Diurnal
- Long-period
- Over 20 constituents may be required for accurate prediction

4 most important constituents

Constituent	Symbol	Period
Lunar semi-diurnal	M_2	12.42h
Solar semi-diurnal	S_2	12.00h
Luni-solar diurnal	K_1	23.93h
Principal lunar diurnal	O_1	25.82h

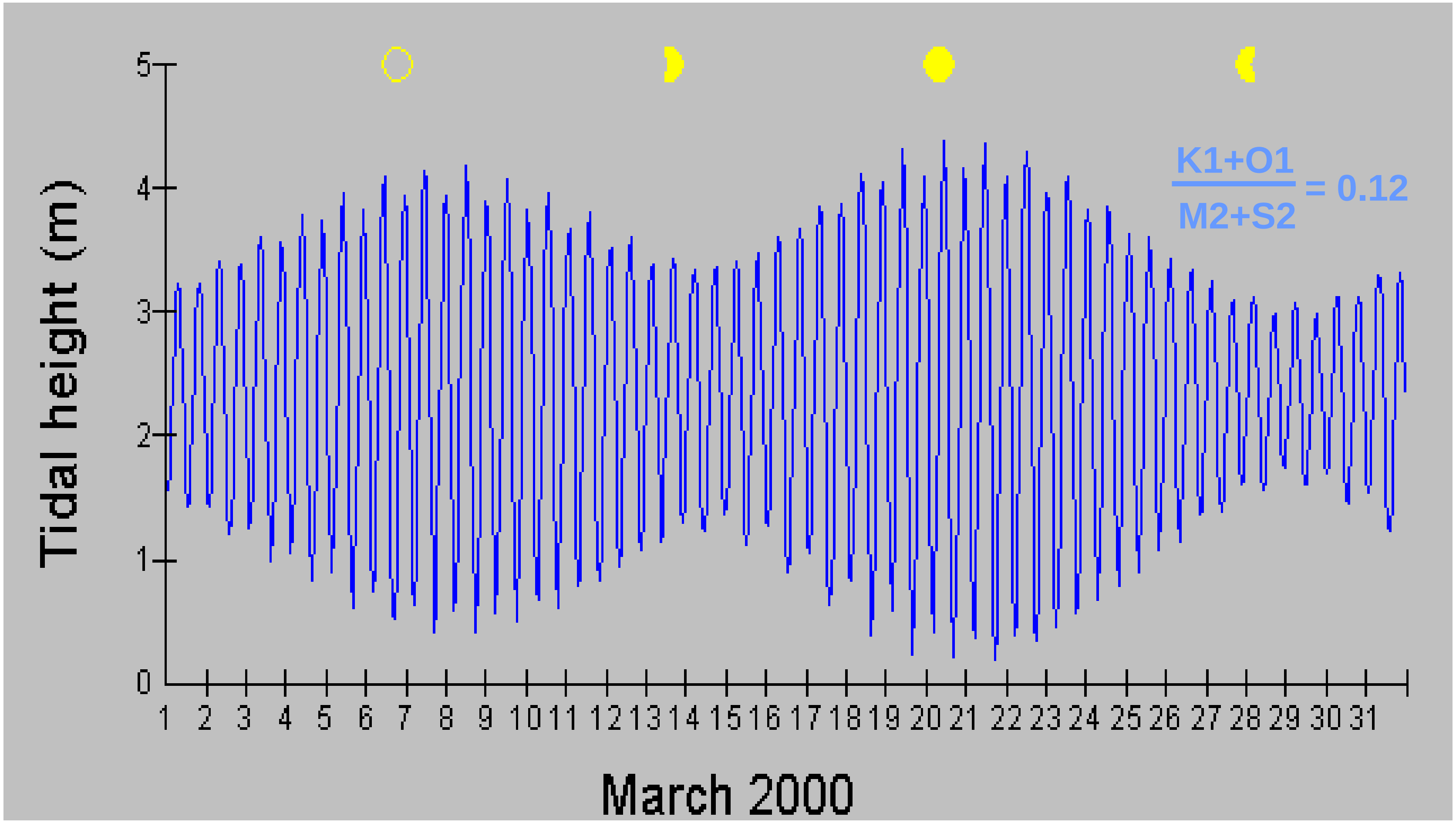
Due to the earth's morphology, a different approach is needed for tidal prediction.

Tides for March 2000 - Tagus Estuary



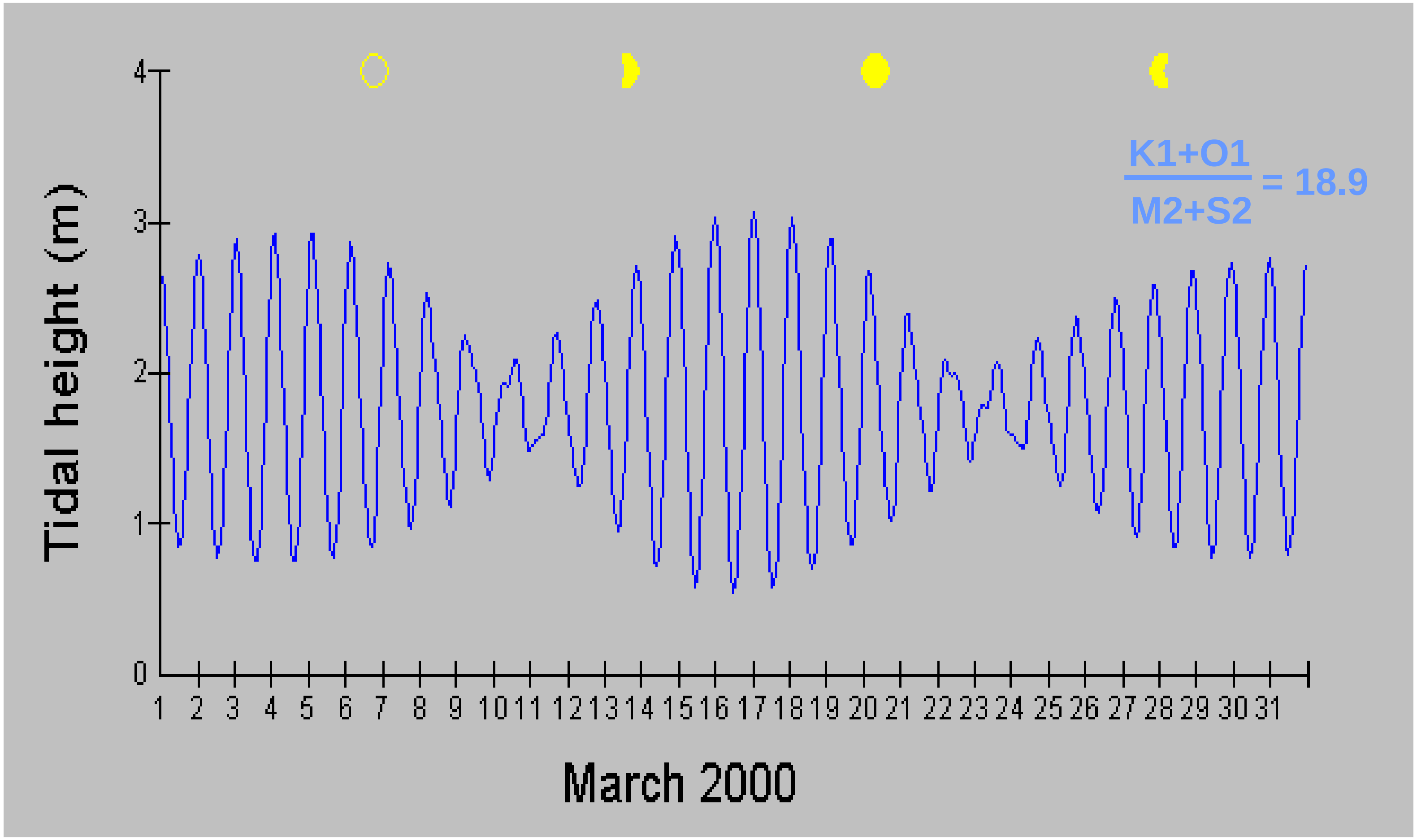
Regular semi-diurnal tide, M2 + S2 are much more important than diurnal harmonics.

Tides for March 2000 – Dublin Bay



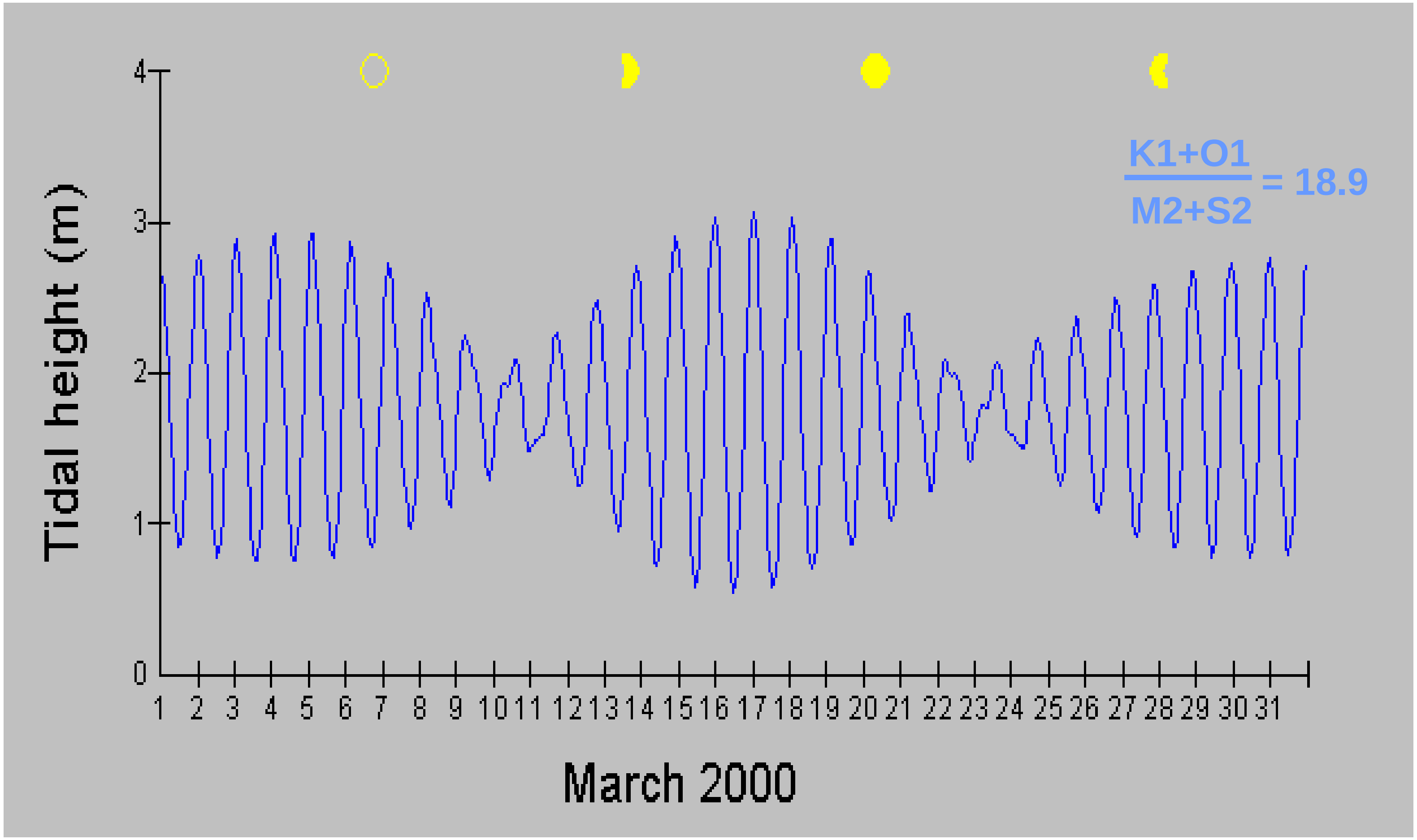
Regular semi-diurnal tide, M2 + S2 are much more important than diurnal harmonics.

Tides for March 2000 – Do Son (Vietnam)



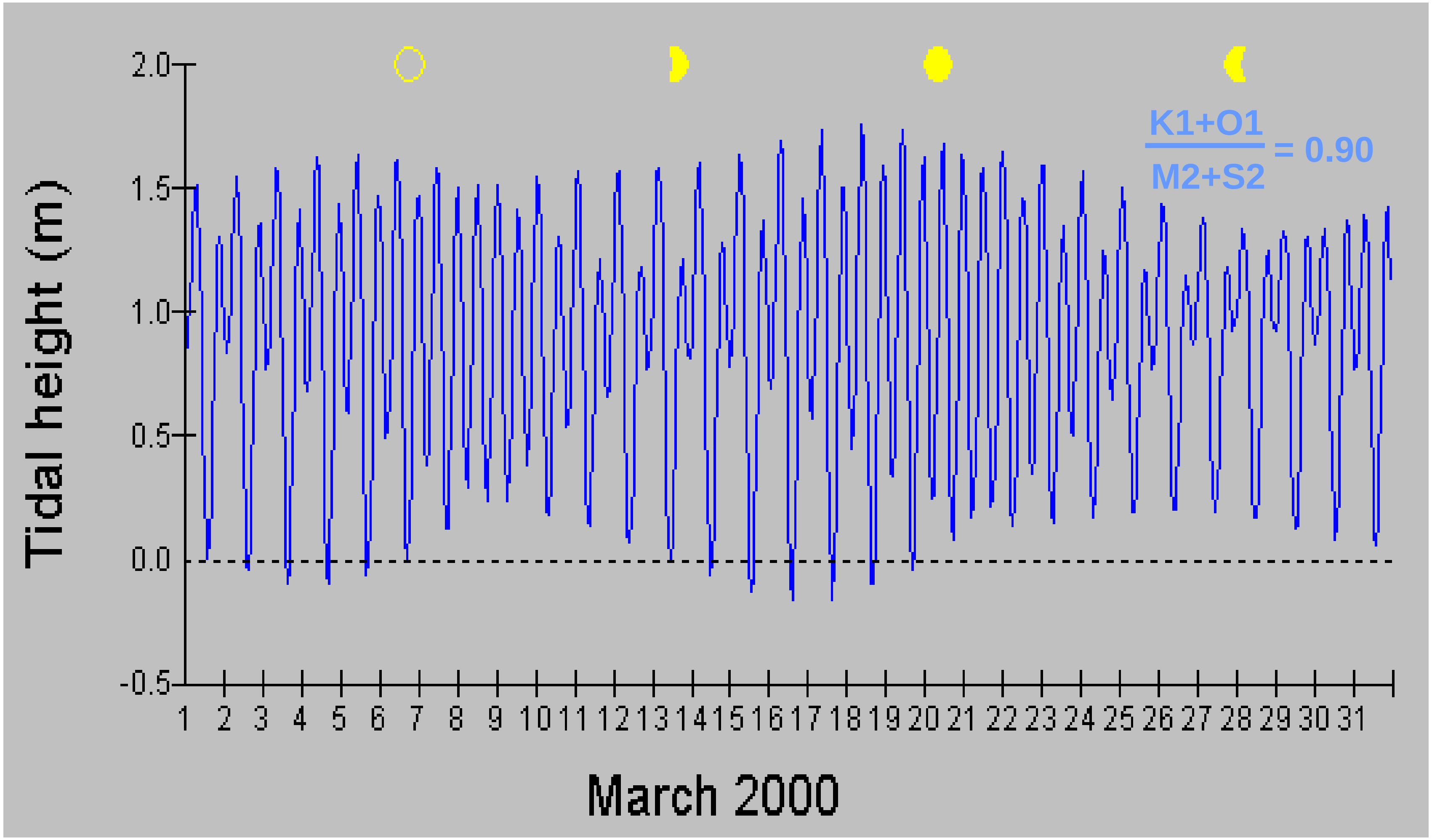
Diurnal tide, M2 + S2 are much less important than diurnal harmonics.

Tides for March 2000 – Manila (Philippines)



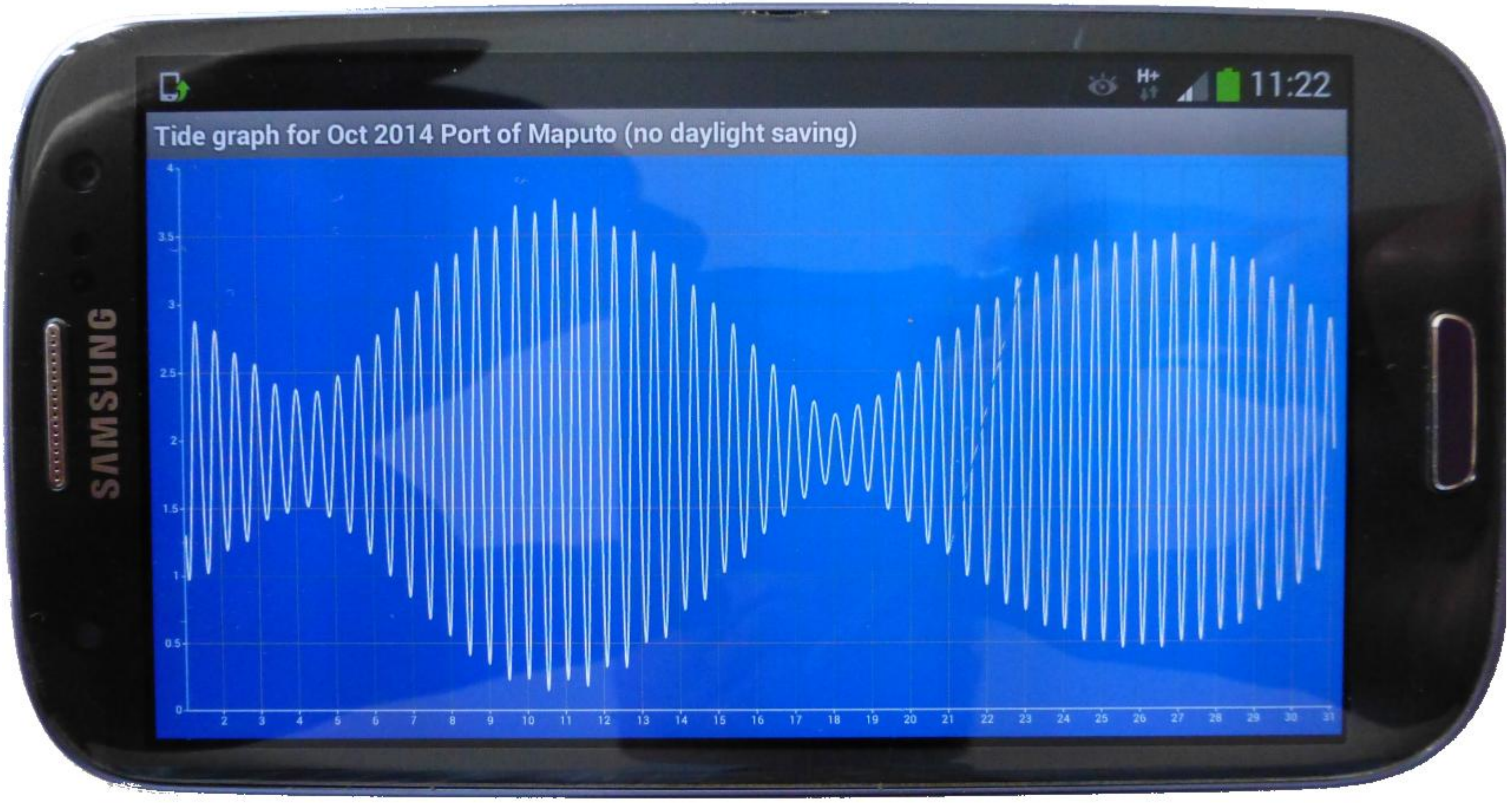
Diurnal tide, M2 + S2 are much less important than diurnal harmonics.

Tides for March 2000 – San Francisco Bay



Semi-diurnal tide with diurnal inequality.

Tides for Maputo
October 2014



Ferreira et al., 2012. Encyclopedia of sustainability science and technology, Springer, *2012*.

Bay of Fundy
Extreme tidal range (>16 m max)

Low tide

High tide

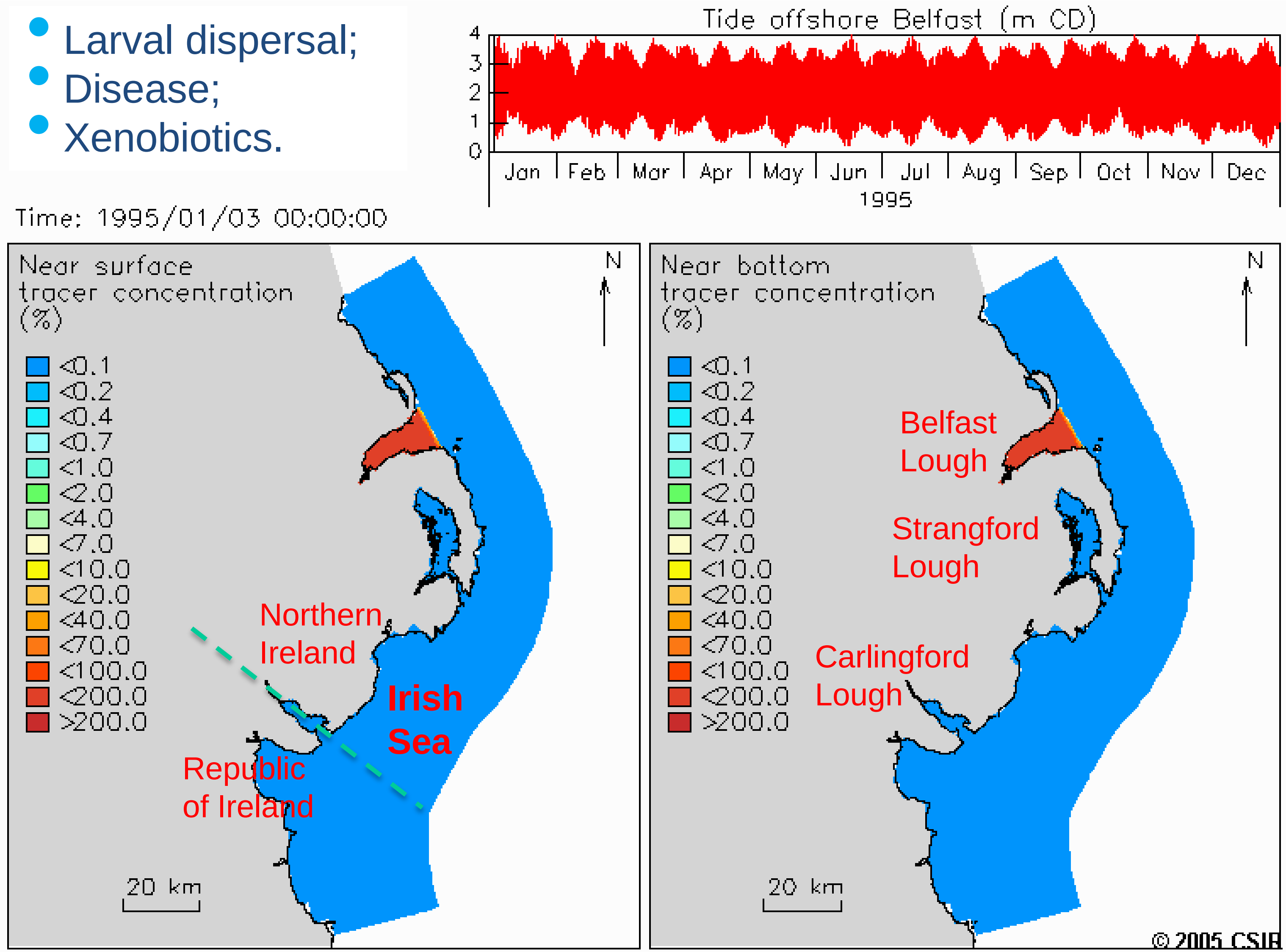
Resonance effects due to the length of the bay cause the highest tides in the world.

http://www.bayfundy.net/hightides/hightides.html

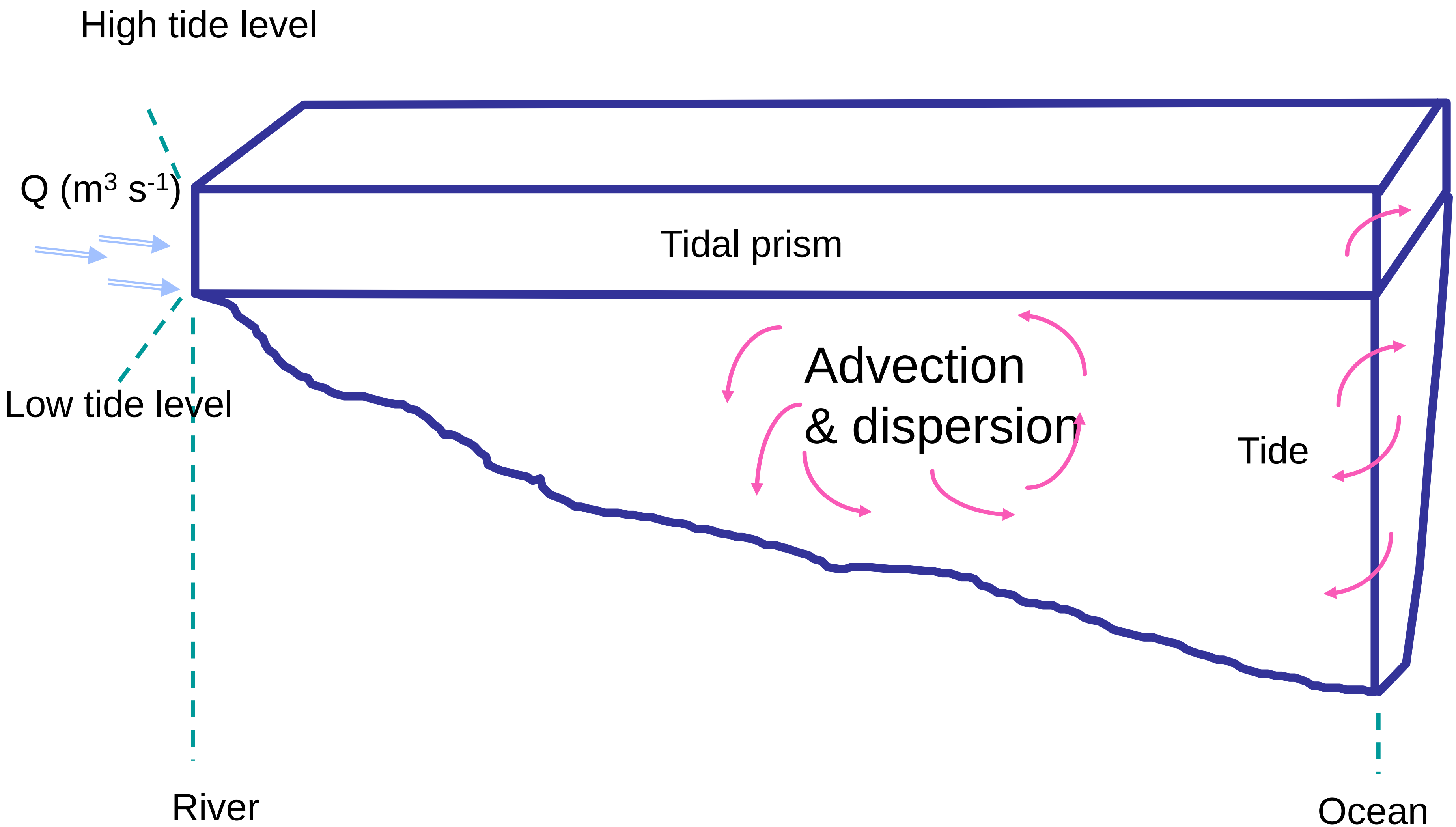
Connectivity of coastal systems

Example: Circulation model – connected systems

- Larval dispersal;
- Disease;
- Xenobiotics.



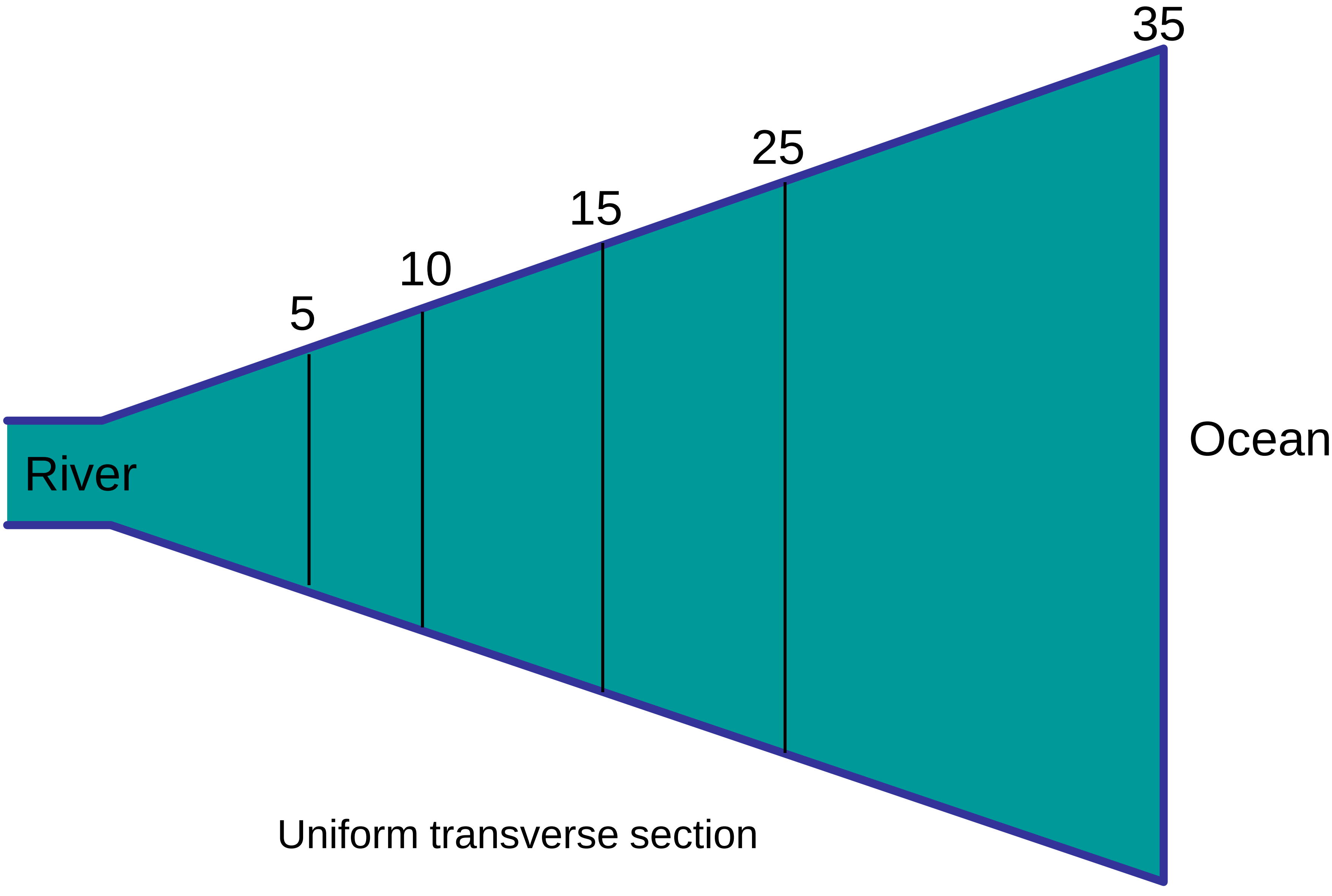
General scheme of an estuary



Estuaries are the most complex surface water systems on the planet.

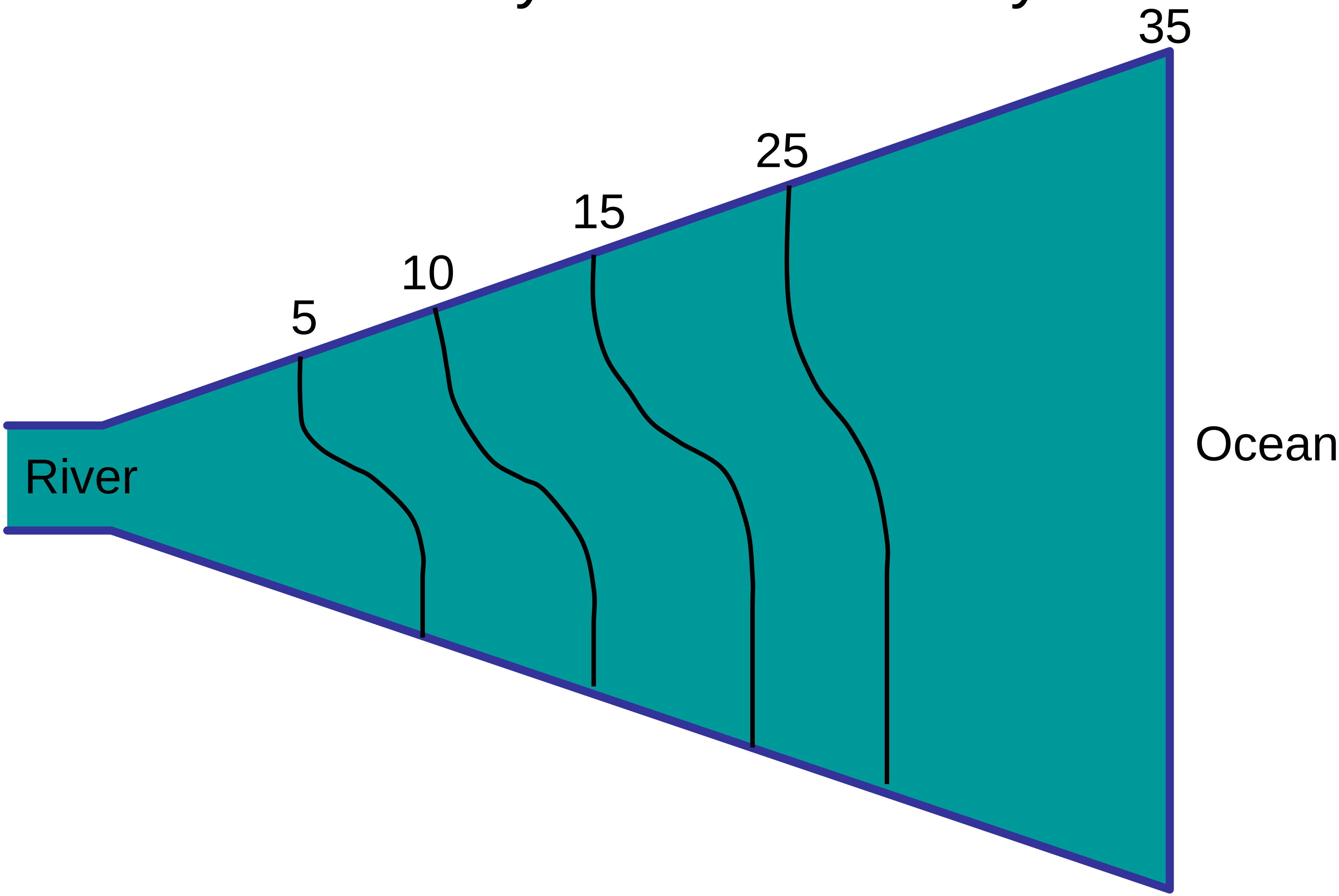
http://insightmaker.com/insight/6659

Longitudinal distribution of salinity



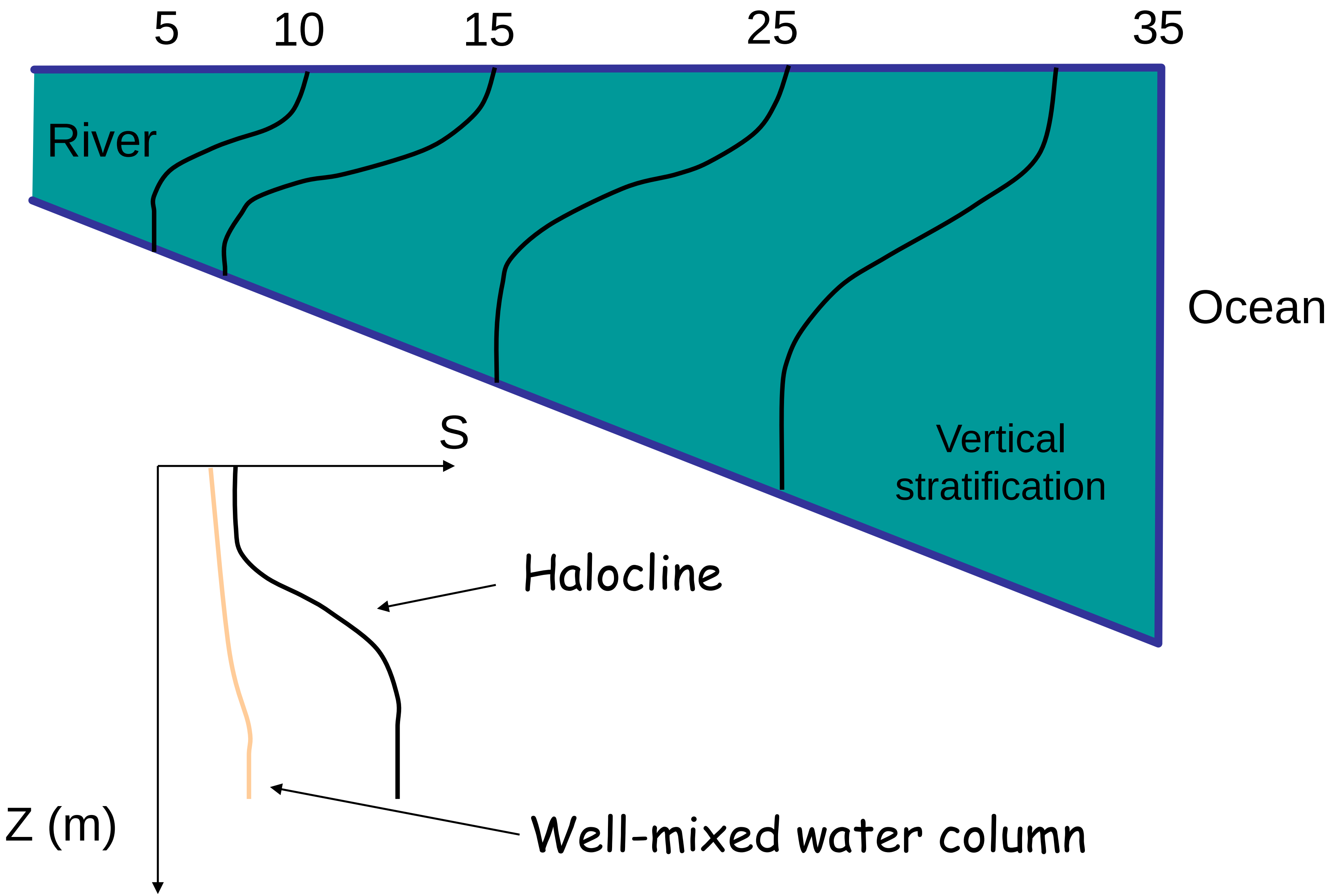
The salinity gradient from river to mouth is not constant.

Laterally stratified estuary



The isohalines suggest the ebb occurs mainly in the southern part of the system.

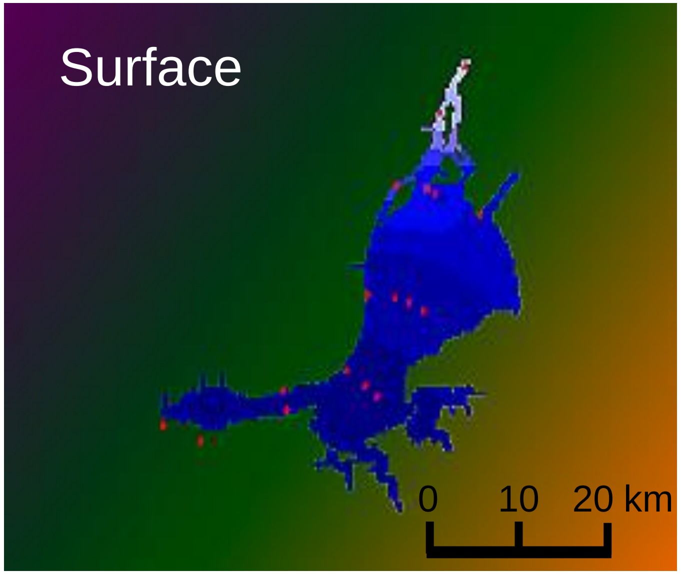
Vertical distribution of salinity in an estuary

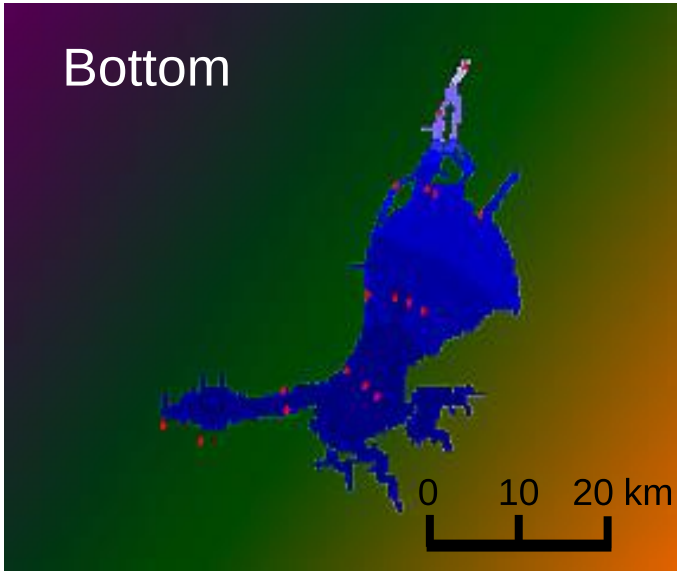


A significant input of freshwater is needed to impose vertical stratification.

GIS - salinity

Summer





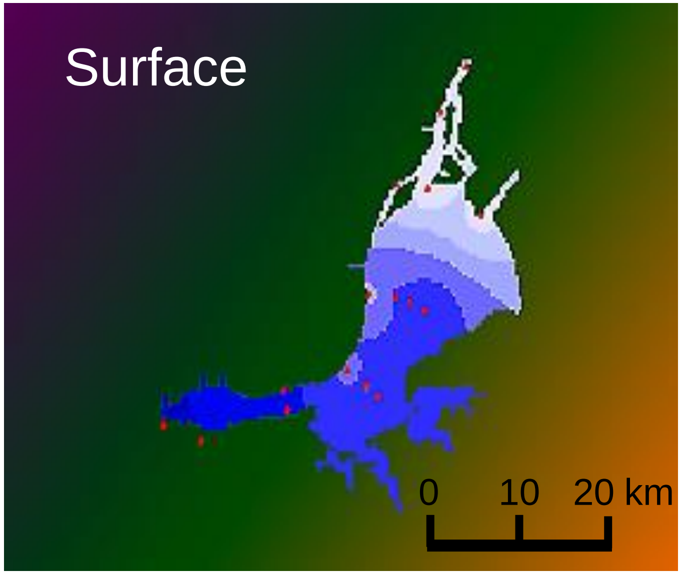
Summer Salinity (psu)

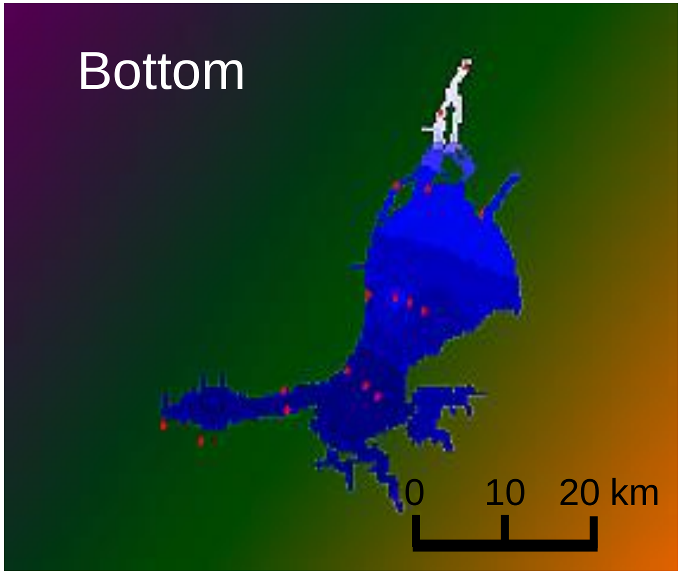
- 0 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 27.5
- 27.5 - 30
- 30 - 32
- 32 - 34
- 34 - 36
- No Data

Winter Salinity (psu)

- 0 - 2.5
- 2.5 - 5
- 5 - 7.5
- 7.5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- 30 - 36
- No Data

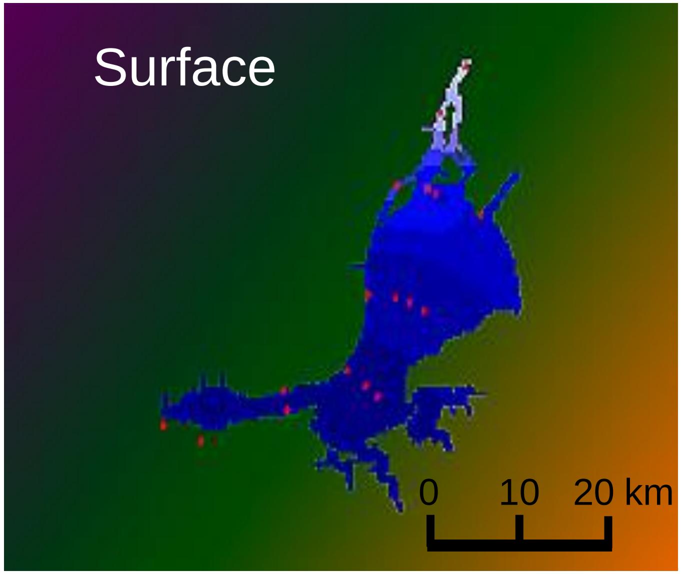
Winter



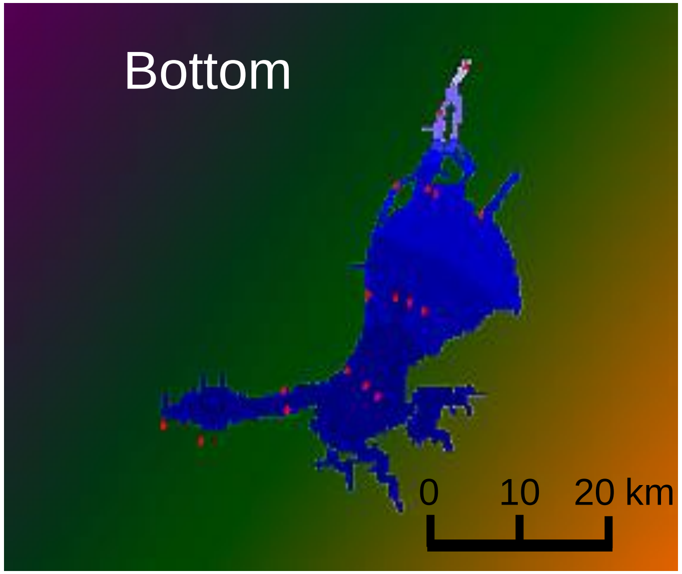


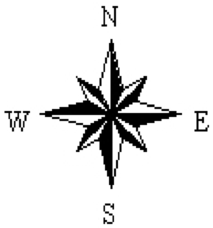
The Tagus estuary is much more saline in summer, particularly at the surface.

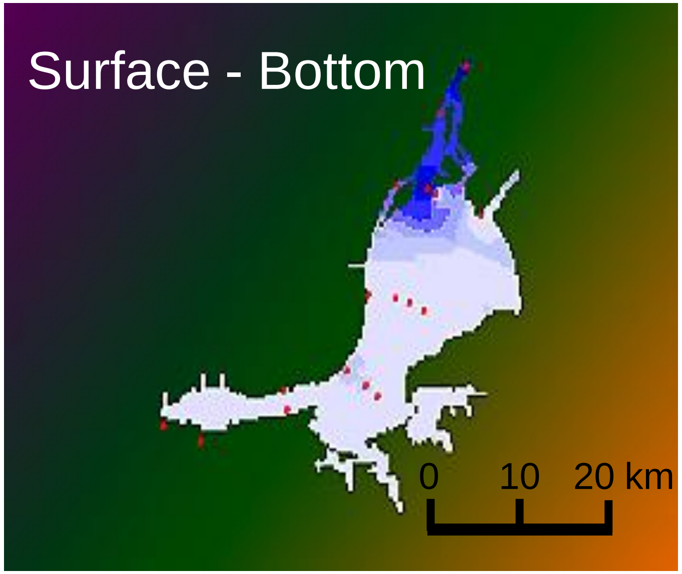
GIS ‘layer algebra’ – Tagus Estuary (summer)



Salinity (psu)
- 0 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 27.5
- 27.5 - 30
- 30 - 32
- 32 - 34
- 34 - 36
- No Data



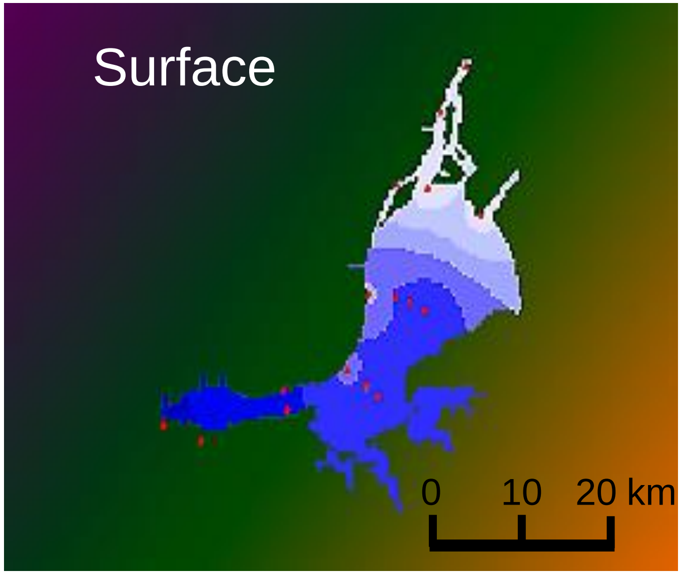


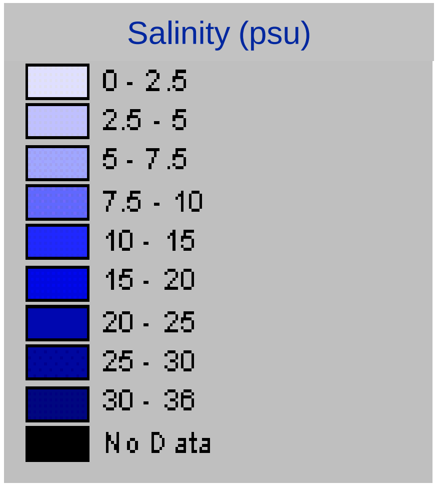


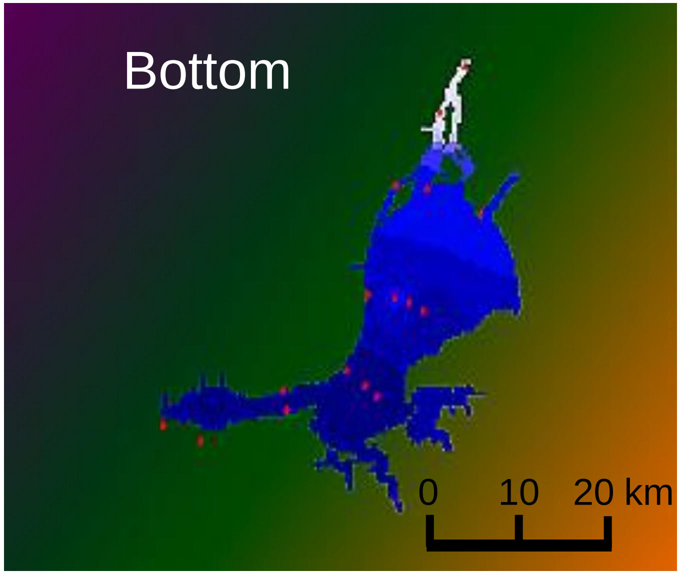
Surface - Bottom Salinity (psu)
- -36 - -10
- -10 - -5
- -5 - -4
- -4 - -3
- -3 - -2
- -2 - -1.5
- -1.5 - -1
- -1 - -0.5
- -0.5 - 0
- No Data

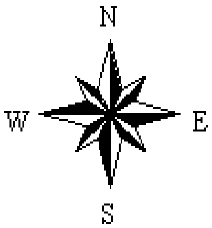
The water column is vertically homogeneous.

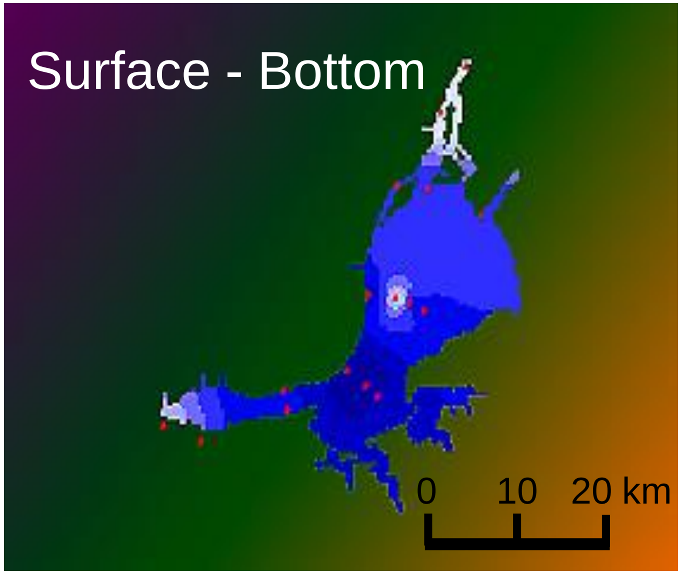
GIS 'layer algebra' – Tagus Estuary (winter)

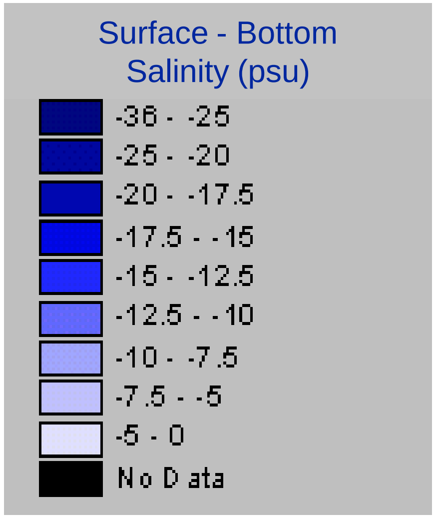






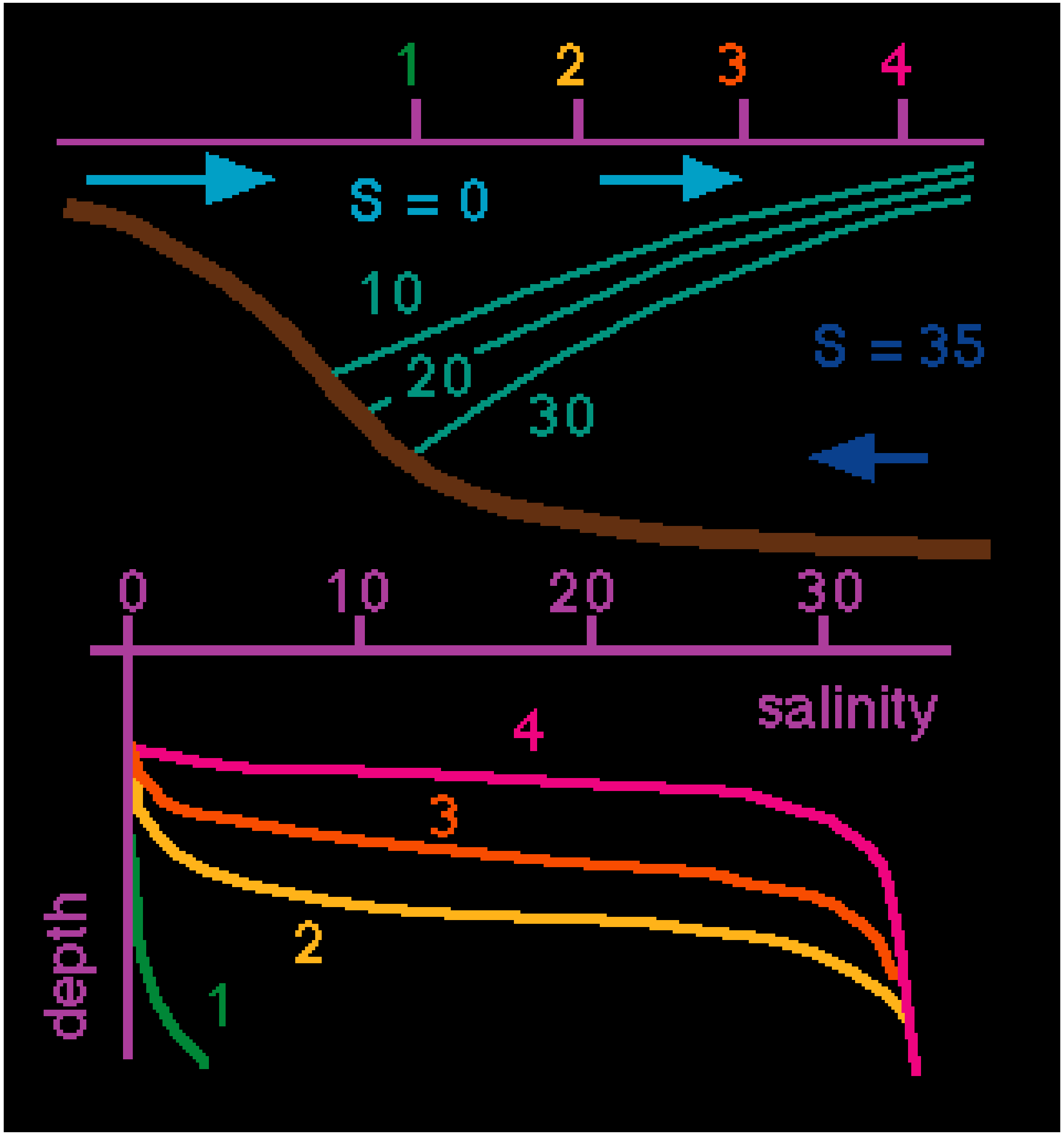






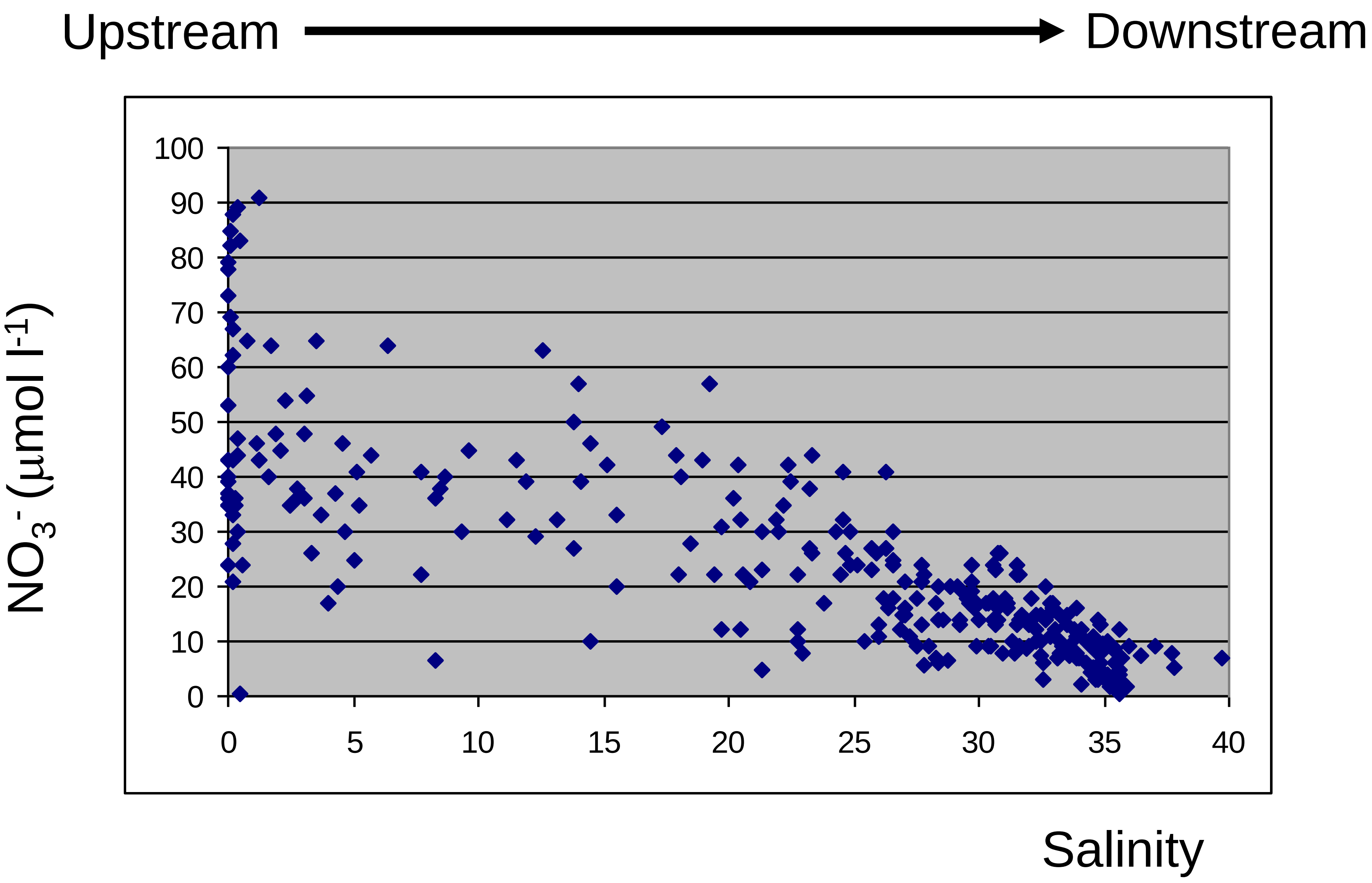
A much more pronounced stratification is observed.

Salt wedge estuary



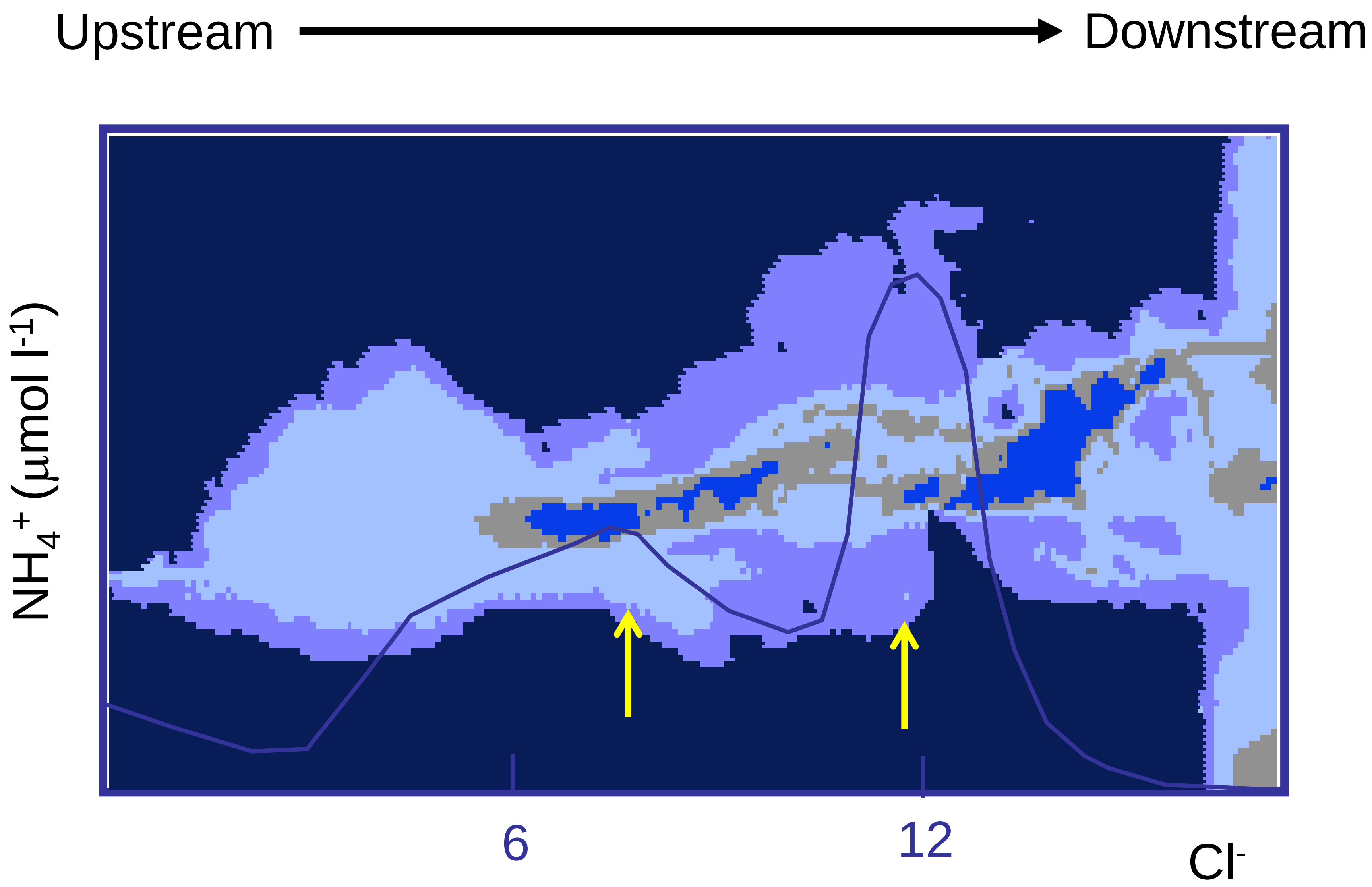
Freshwater from the rivers and salt water from the ocean hardly mix.

Tagus Estuary - dilution diagram for nitrate



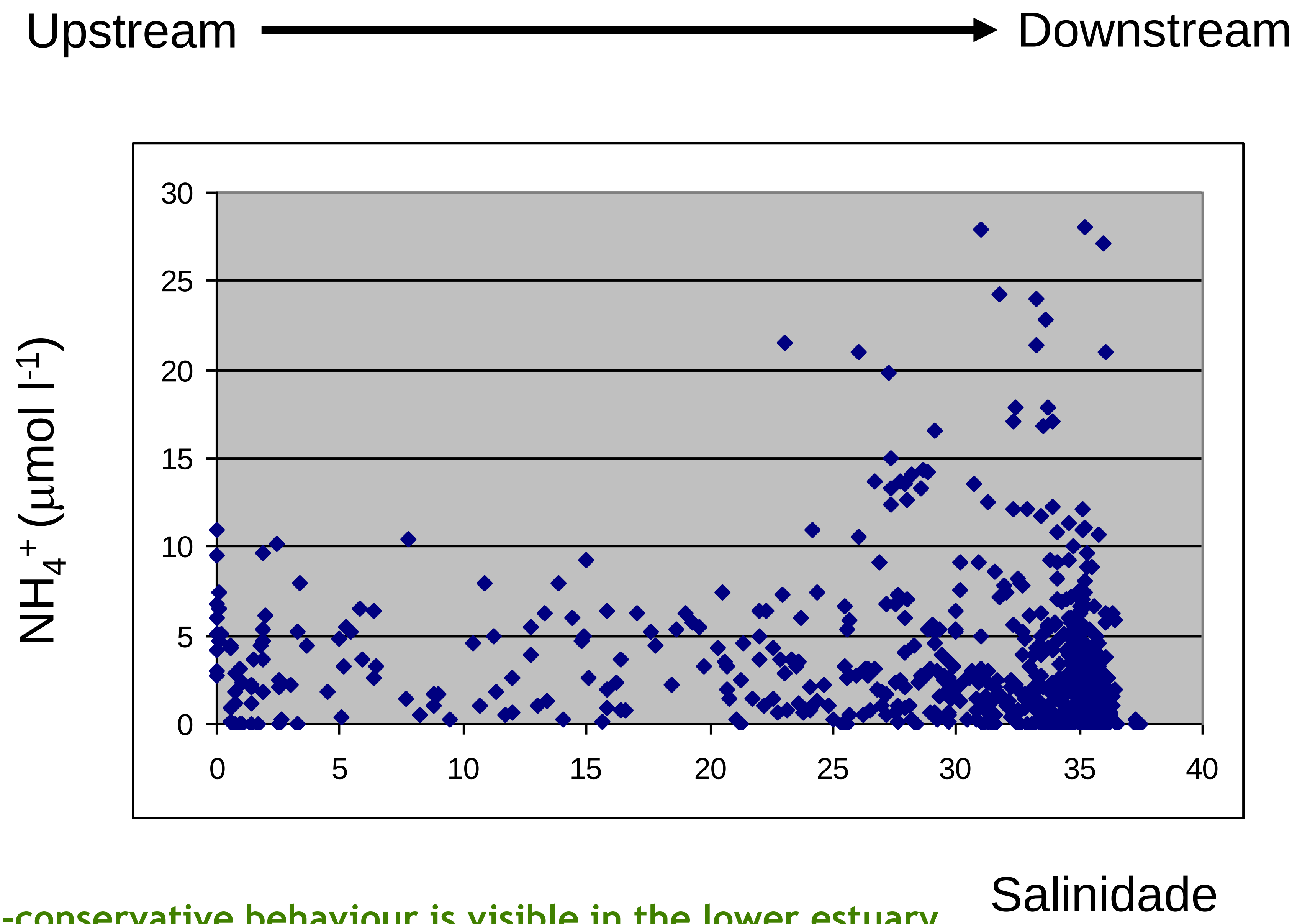
Non-conservative behaviour is visible in the middle estuary.

Dilution diagram for ammonia



Non-conservative behaviour is visible in the middle estuary.

Sado Estuary - dilution diagram for ammonia



Non-conservative behaviour is visible in the lower estuary.

Basic estuarine calculations

Vertical stratification

$$Vs = \frac{\Delta S}{Sm}$$

- Indicator of estuarine mixing
- Indicator of potential oxygen problems

Estuary number

$$En = \frac{Q}{Tp}$$

- Indicator of ocean dilution
- Indicator of circulation

Freshwater residence time and flushing rate

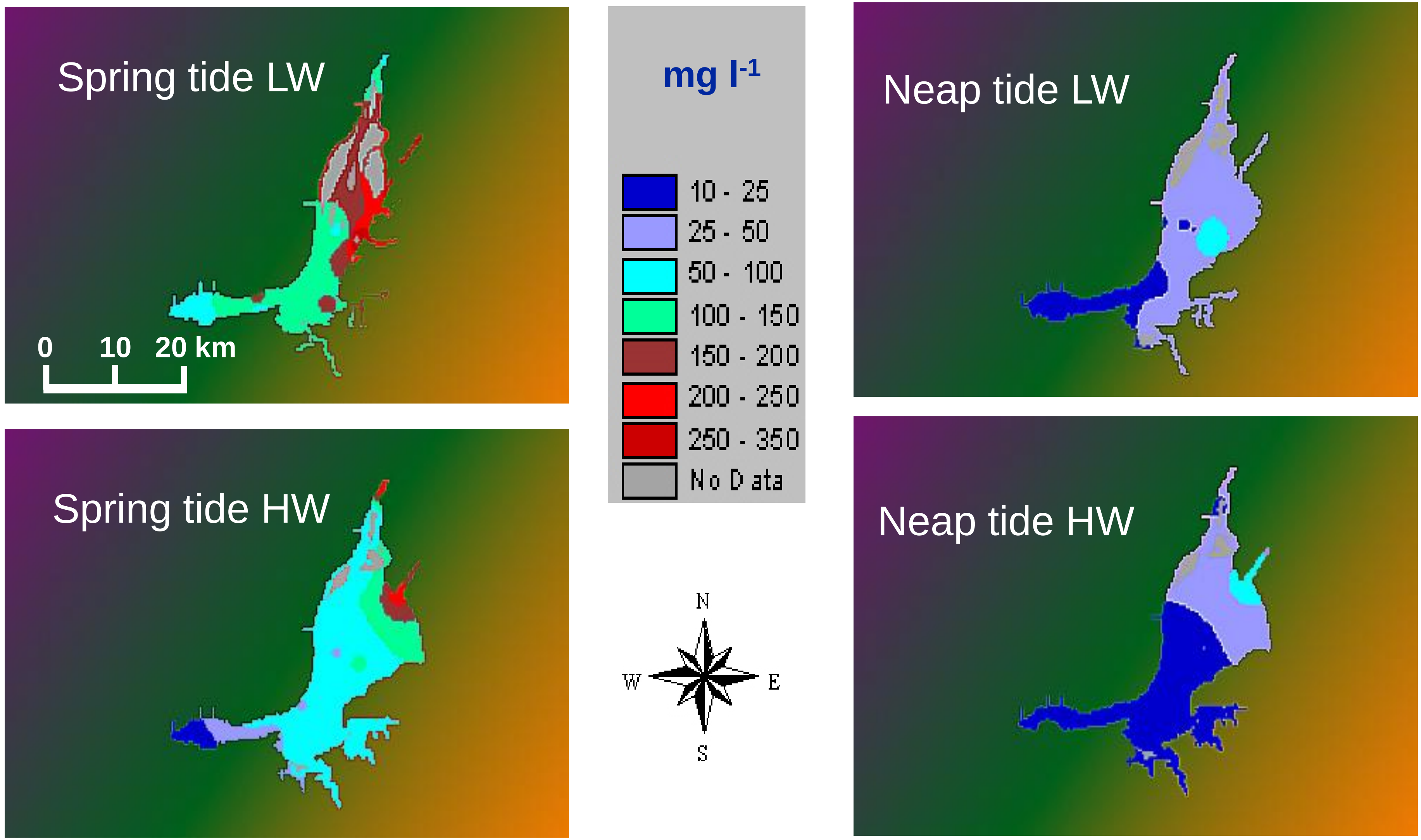
$$Tr = \frac{Vf}{Q}$$

- Indicator of pollutant dispersion
- Indicator of potential oxygen problems

Tagus estuary – space shuttle image

Export of suspended matter on the ebb tracks a gyre in the coastal area.

Tagus Estuary GIS – suspended particulate matter



Higher current speeds over spring tide make the estuary much more turbid.

Surface area to volume ratio – sinking rates

Sea surface

z (depth)

Fall velocity

$$W = \frac{2}{9}\frac{g(D-d)r^2}{u}$$

1mm cube
surface area = $6mm^2$
volume = $1mm^3$
$\frac{\text{surface area}}{\text{volume}} = 6$

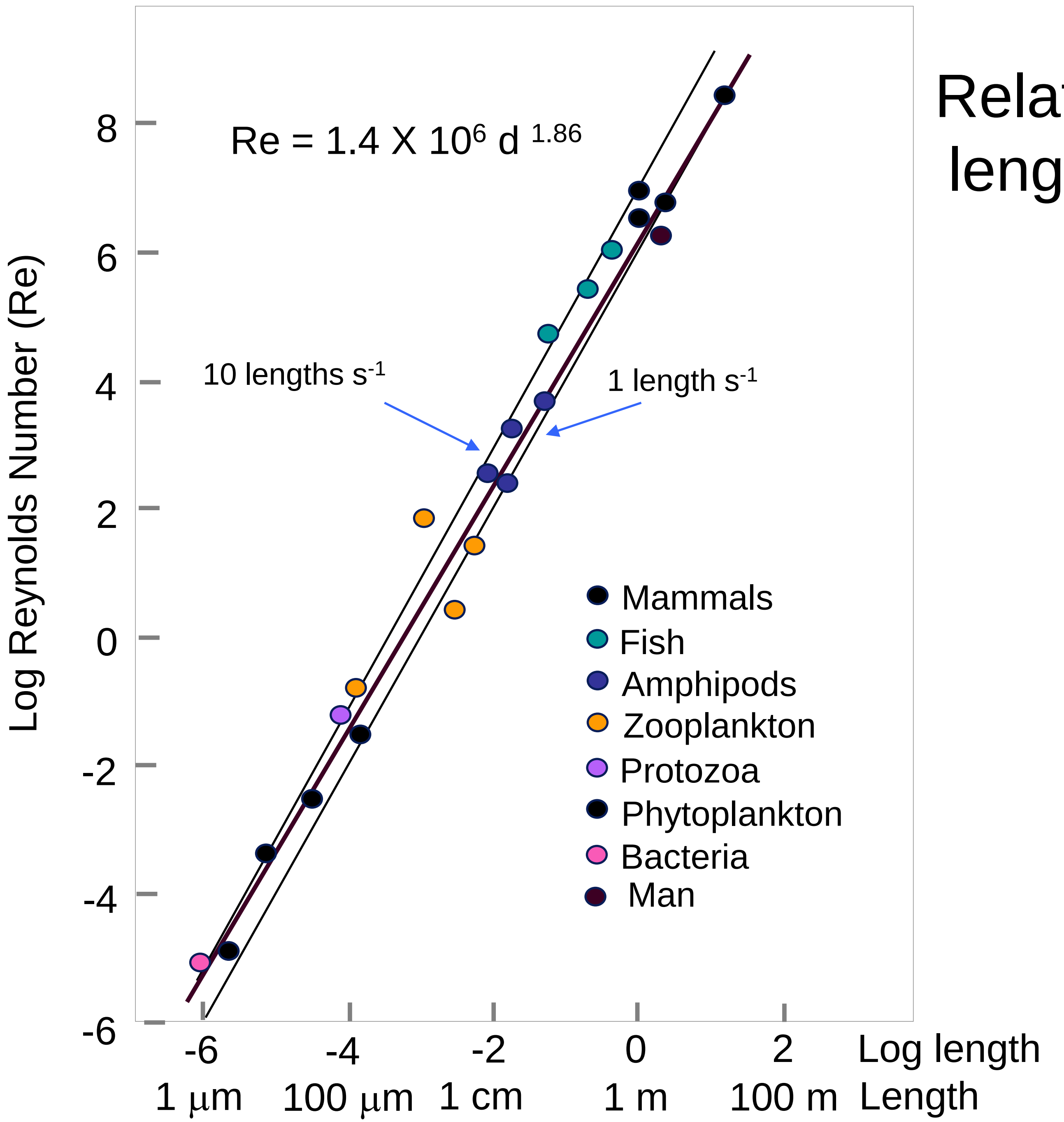
10mm cube
surface area = $600mm^2$
volume = $1000mm^3$
$\frac{\text{surface area}}{\text{volume}} = 0.6$

Relationship between forces

$$Re = \frac{ud}{v}$$

Bigger organisms fall faster, turbulence keeps phytoplankton in the photic zone.

Relationship between length and Reynolds number



The Reynolds number of organisms increases with size.

Reynolds number for different organisms

Organism	Re
Large whale ($10\ ms^{-1}$)	300 000 000
Tuna ($10\ m\ s^{-1}$)	30 000 000
Duck flying ($20\ ms^{-1}$)	300 000
Dragonfly ($7\ m\ s^{-1}$)	30 000
Copepod in a pulse of $20\ cm\ s^{-1}$	300
Smallest flying insects	30
Invertebrate larva 0.3mm long at $1\ mm\ s^{-1}$	0.3
Sea urchin sperm advancing the species at $0.3\ mm\ s^{-1}$	0.03

Vogel, S, 1981 - Life in moving fluids. The physical biology of flow. Willard Grant Press, Boston, 352 pp.

Re = ud/v (2500 ~ threshold between laminar and turbulent flow)

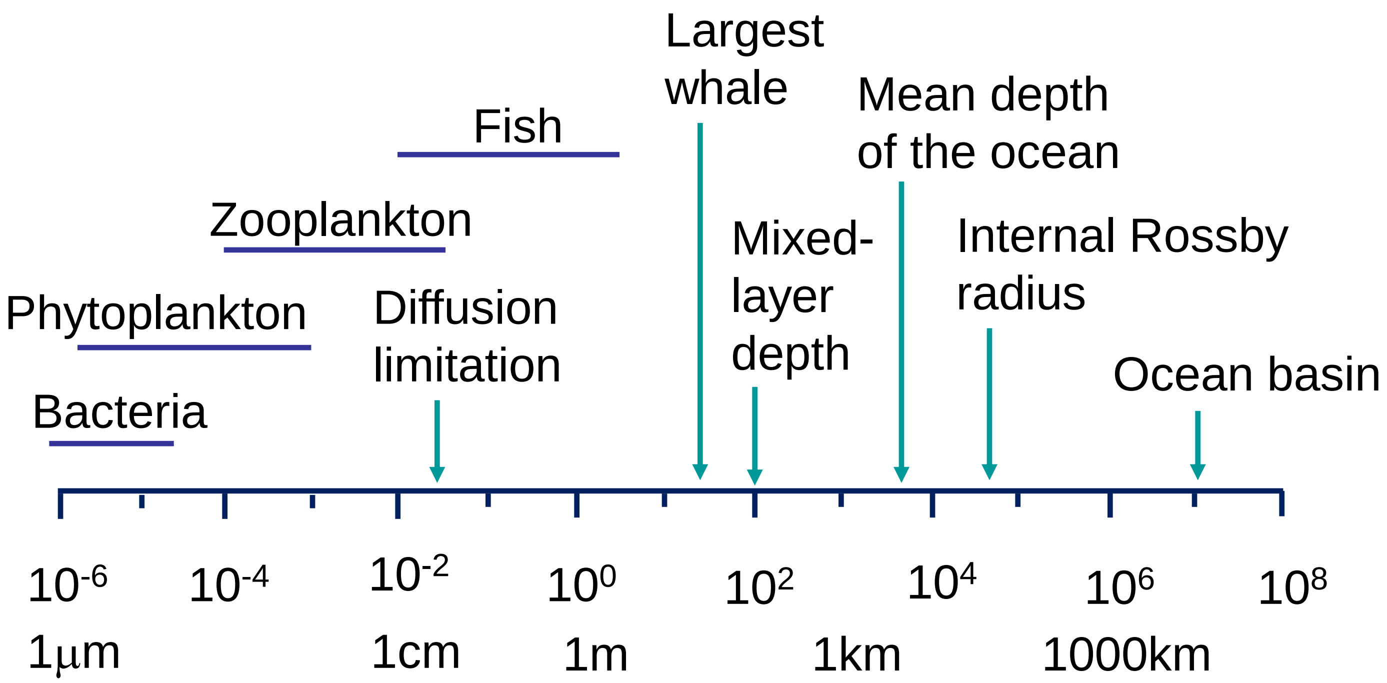
$Re = 1.4 \times 10^6\ d^{1.86}$

Relationship between length and swimming speed

$u\ (m\ s\text{-}1) = 1.4 \times d^{0.86}$ (kinematic viscosity = $10^{-6}\ m^2\ s^{-1}$)

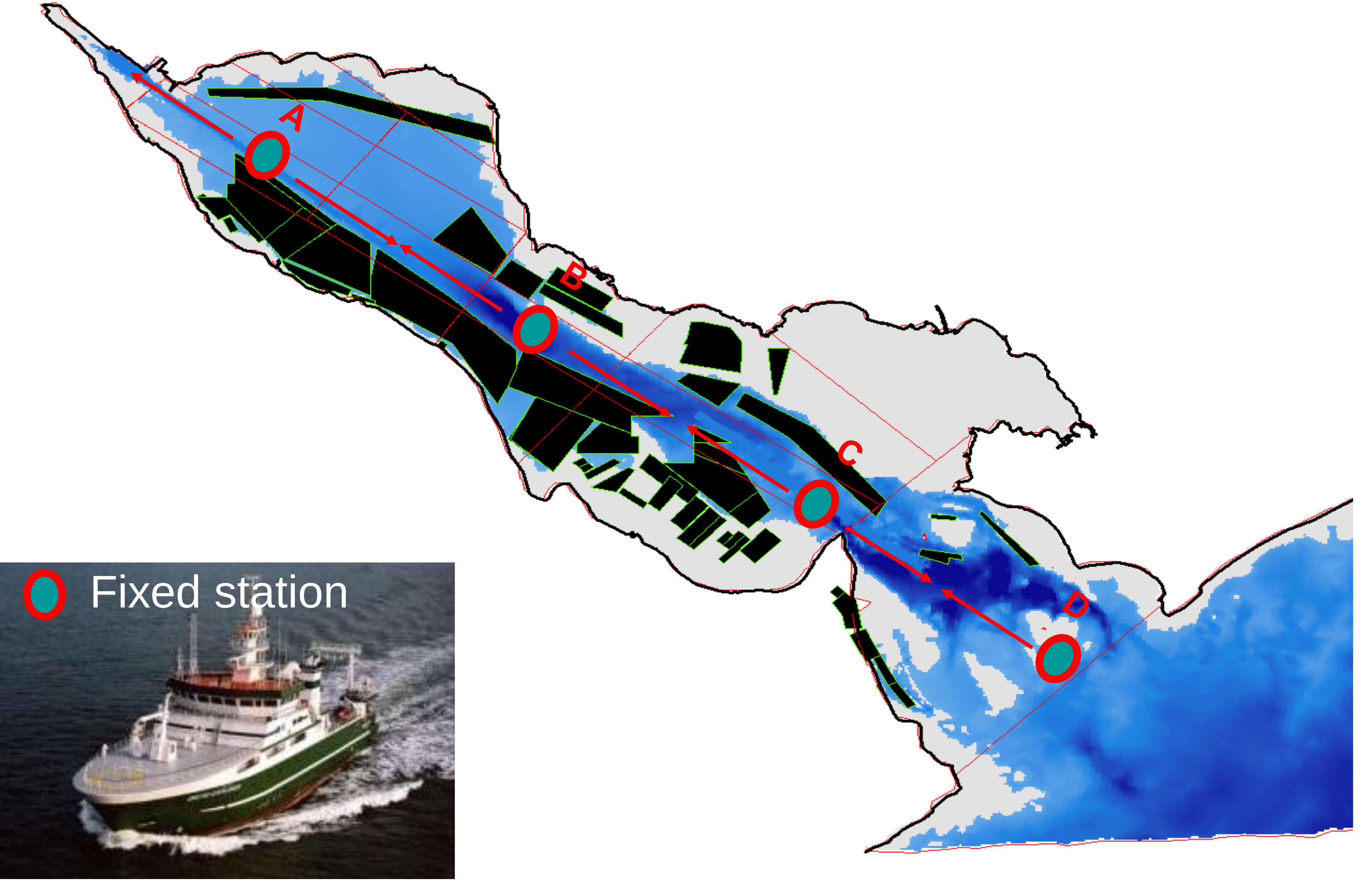
Big fish swim faster than little ones.

The length scale
1μm-100000 km



Mann & Lazier, Dynamics of Marine Ecosystems, Blackwell 1991

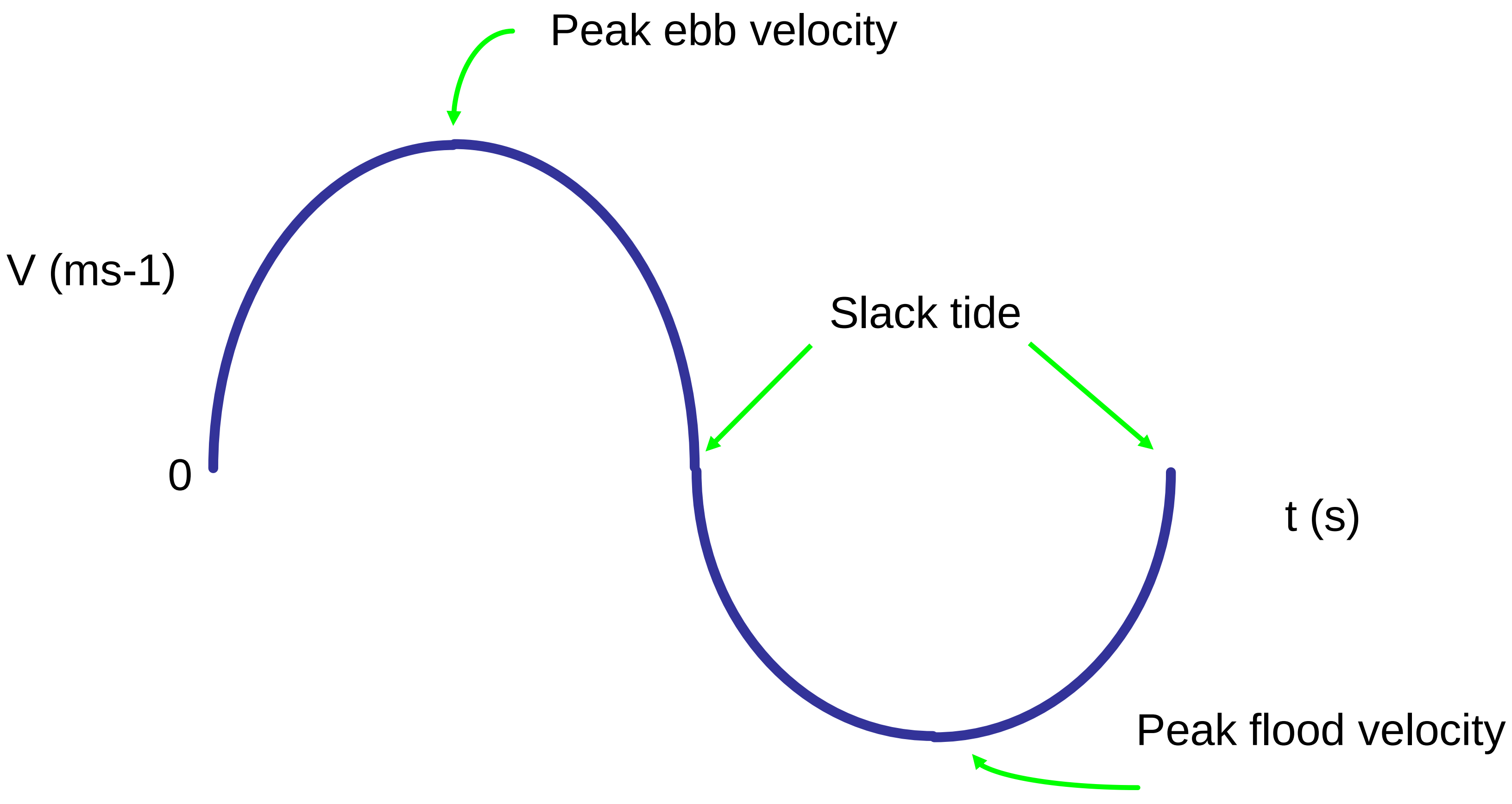
Eulerian sampling approach



Fixed stations sampled over a tidal cycle.

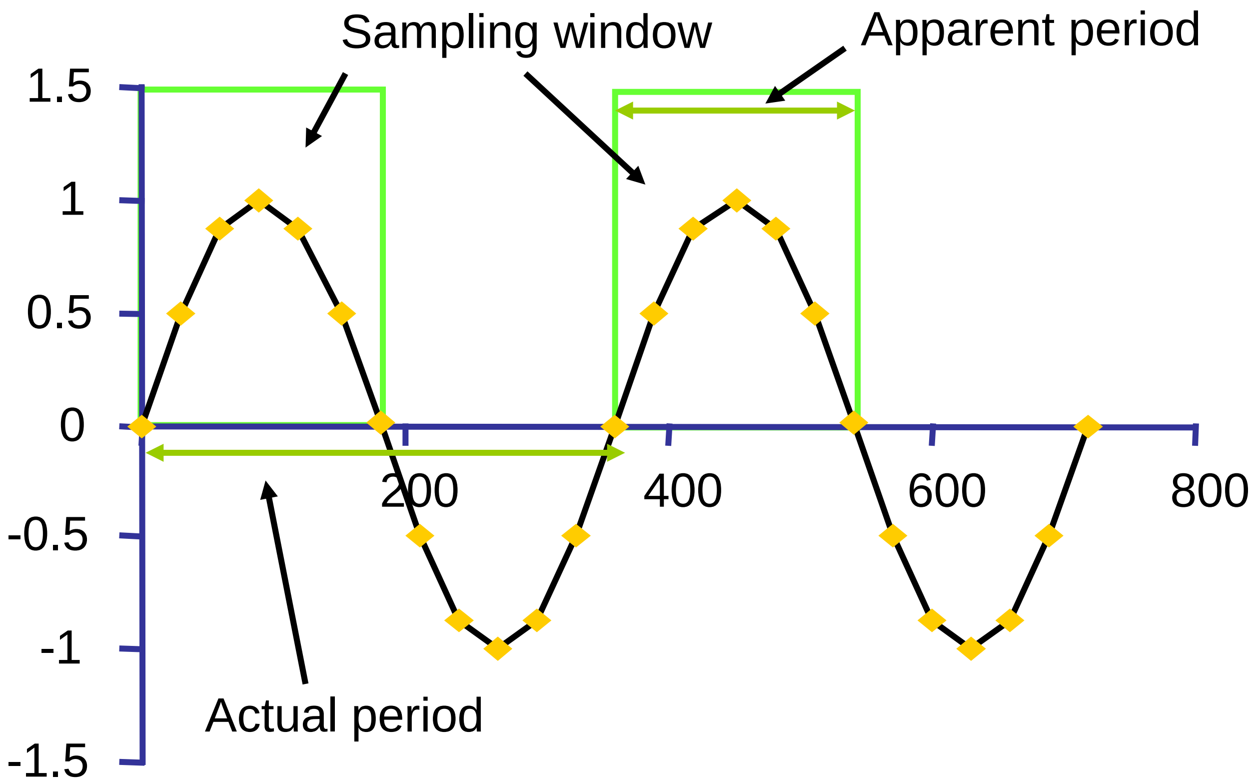
Eulerian sampling - integration

$$\int V\,dt = h/3\,(y0+4y1+2y2+\ldots+4y_{n-1}+y_n)$$



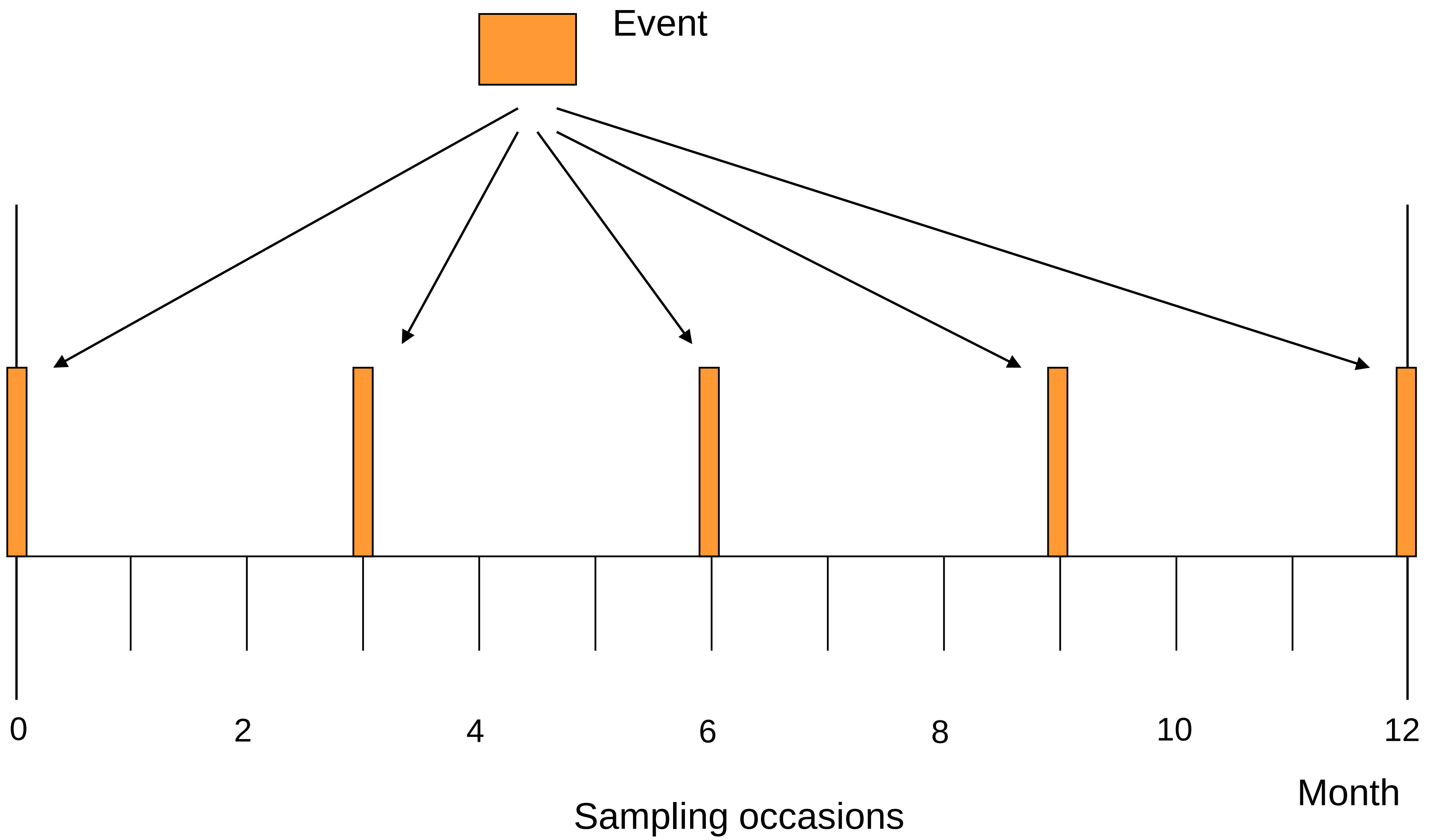
Integration of velocity gives information on tidal excursion.

Sampling period and actual period



Actual period is double the apparent period.

Sampling period and event occurrence



Event occurs seasonally (every 3 months) but appears to occur every six months.

Synthesis

- The physics of the coastal ocean is complex, and largely determines the distribution of both dissolved and suspended particles
- Hydrodynamics therefore drives a significant part of marine, estuarine, and freshwater ecology
- More straightforward relationships between pressure and state can be established in freshwater systems
- Management of estuarine and coastal water bodies is usually complex and may give unexpected results

All slides

http://ecowin.org/aulas/mega/pce